4-1990

The Effect of Temperature on Survival, Growth and Feed Conversion of Black Bullhead (Ictalurus melas)

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The Effect of Temperature on Survival, Growth and Feed Conversion of Black Bullhead (*Ictalurus melas*)

A Thesis Presented to the Faculty of the Department of Biological Sciences of the State University of New York College at Brockport in Partial Fulfillment for the Degree of Master of Science

by

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April 1990

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BIOGRAPHICAL SKETCH

Samuel Jafet Renyaan was born [redacted] in Sorong (Bintuni), Irian Jaya, Indonesia. He graduated in 1967 from Sorong High School, from Surabaya Teacher College in 1974 with Bachelor of Arts (BA), and from Malang Teacher College for Doctorandus (Drs) in 1978.

In 1979, Mr. Renyaan accepted a position in Biology in the Science and Mathematics Department of Teacher College of Cendrawasih University. Besides teaching he also served as:

1. Secretary of the Department : 1981 - 1983.
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In the Fall of 1986 he attended the English Language Internship Course at SUNY Buffalo. In Spring 1987 he was temporarily enrolled in the Educational Department at SUNY Albany. He enrolled at Biology Department (Behavioral Ecology) at SUNY Albany from Summer 1987 - Summer 1988. In Fall 1988 he moved to the Department of Biological Sciences of SUNY College at Brockport.

On [redacted] Mr. Renyaan married Sulistya Rachmawati, a dentist working at Abepura Health Center. With God's Grace, she delivered Axelon Samuel Renyaan on [redacted]

DEDICATION

To Hwa, my Wife

and Axel, my Son

Who Have Taught me How to be a Father and a Scholar

To Our families

and My Friends in Irian Jaya

Who always inspired and encouraged me to be a Scholar

ACKNOWLEDGMENTS

First I thank JESUS, my LORD, who provided me with Love and Wisdom during my Master of Science Program.

I thank Dr. T. Raka Joni and Dr. Agustiar Nur Syah M.A, P2LPTK Project Leaders from Indonesian Government, who provided me with the opportunity and time to finish my Master's Program in Biological Sciences. Additionally, I thank Mr. James Kelly, the ISMEP staff, and Dr. Walter Gibson (SUNY Center at Albany, my Indonesian Co-Adviser) for facilities and support, particularly between me and my Government.

I would like to thank Dr. Joseph Buttner, my major advisor, who provided help and advice during my tenure at Brockport. Dr. Joseph Makarewicz and Dr. James Haynes, reviewed my thesis and served on my graduate committee.

I am indebted to Dr. Mary Jo Orzech, Computer Adviser at SUNY Brockport, and Dr. Morris Beers, Department of Education and Human Development, SUNY College at Brockport, for the time and support they shared, and for the use of their computer facilities. Special thanks to Mr. Mark Clapsadl, Technician at SUNY College at Brockport, whose advise and criticisms were very helpful during my study.

Finally, I would like to thank Sulistya Rachmawati, my wife, and Axelon Samuel Renyaan, my son, without whose love and constant encouragement, this project could not have been completed.

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ABSTRACT

This study was conducted to determine the effects of temperature on survival, growth, food ingested and feed conversion of fingerling black bullhead (Ictalurus melas).

Fish were maintained for nine weeks in reuse systems under controlled environmental conditions (room temperature: 23-26 °C; 0.4-8.4 lux of continuous light) in Wet Laboratory II at SUNY College at Brockport. Each treatment (water temperature of 16, 22, 28 and 34 °C ± 2 °C) was run in triplicate; 416 fish (10-13 cm length; 6-20 g weight) were used. Two PVC tubes (diameter 8 cm; 33-41 cm long) were placed in each fish holding unit to provide cover and reduce stress. Dissolved oxygen was monitored daily. Total ammonia-nitrogen, nitrite-nitrogen and nitrate-nitrogen were monitored weekly. Fish were fed to satiation once daily with Purina Trout Chow #5.

Best survival (90.5 %), growth (124.5 %) and feed conversion (1.1) were observed at 28 °C. Survival (80.7 %), growth (43.4 %) and feed conversion (4.6) were reduced at 22 °C. At 16 °C fish survived well (86.6 %), feed conversion was low (1.4), and growth was relatively good (22.3 %). At 34 °C fish were stressed; survival (59.0 %), growth (29.8 %) and feed conversion (3.0) were

poor. "Social appetite" at 22 and 28 ^{o}C was normal, but at 16 and 34 ^{o}C fish exhibited abnormal behavior.

INTRODUCTION

The black bullhead (*Ictalurus melas*) occurs naturally in the north central United States and is endemic to New York (Scott and Crossman 1973; McLarney 1984). Throughout its range the fish is eagerly sought and readily consumed by many anglers and consumers (McLarney 1984). Procedures to culture black bullhead successfully in cages have been identified and cage-reared fish have been marketed (Buttner 1988; Buttner, Department of Biological Sciences, SUNY College at Brockport, personal communication). To facilitate commercial production of black bullhead it is necessary to reduce production costs and promote fish growth. Information on the preferred temperature for optimal growth and feeding rates for black bullhead are needed.

Temperature is an important independent variable that can effect fish growth (Kinne 1960; Elliot 1975a, b; Brett 1979). Culture of fishes can be enhanced if they are reared at, or near, their optimal temperature. For instance, optimal growth for channel catfish (*I. punctatus*) occurs at 30 ^{o}C and substantial weight gains can be attained between 18-34 ^{o}C (Andrews and Stickney 1972; Stickney 1986). Brown bullhead, *I. nebulosus*, grow at 10-30 ^{o}C with a better growth at 20-30 ^{o}C than 10-30 ^{o}C (Keast 1985). It is known that glycogen in the liver

and other organs of black bullhead increases more at 20-24 ^{o}C than at 10-20 ^{o}C (Ottolengki et al. 1981).

Photoperiod influences feeding behavior in fish. Peak feeding activity in young black bullhead typically occurs between 0200 to 0500 and 2000 to 2300 (Darnell and Meirotto 1965), although feeding can and does occur at other times (Carlander and Clearly 1949; Darnell and Meirotto 1965). Black bullhead apparently feed best in reduced light, though that does not mean they prefer a short photoperiod. Light induces the production of the growth hormones which stimulates the locomotor activities and growth rate (Kwain 1975; Brett 1979). Rainbow trout (Oncorhynchus mykiss) reared at 16h light and 8h dark exhibit reduced growth rate when transferred to a low light intensity culture situation (Kwain 1975). Channel catfish fry (0.07g), I. punctatus, show higher growth rate at 14L than at 10L (Kilambi 1970; cited by Brett 1979). Effect of photoperiod on growth rate depends on fish size and the duration of exposure. At least 6 to 8 weeks are needed for the photoperiod to affect the fish (Brett 1979).

Feeding rate/behavior in black bullhead is also affected by the "hunger drive" (the physiological need for food) and the "social appetite" (psychological need for feeling safe in a group when fish eat or do other activities) (Bowen 1931; Darnell and Meirotto 1965).

Bunching and aggregation behavior are closely correlated with high metabolic rate (Bowen 1931).

Available data suggest that growth of black bullhead is temperature related, that growth occurs at lower temperatures than for channel catfish and that most feeding occurs at night or during reduced light. Validation of these observations and their appropriate application in culture operations could promote survival and growth of cage and pond cultured black bullhead.

The objectives of this study were:

(1) To determine survival and growth of fingerling black bullhead maintained for nine weeks at 16, 22, 28 and 34 ^{o}C;

(2) To determine the effect of temperature on food ingested and feed conversion.

MATERIALS AND METHODS

Fish Source

Fingerling black bullhead used in this study were spawned and maintained in an aquaculture research pond (0.1 hectare) on-campus at SUNY College at Brockport. They were second and third generation fish spawned from parents selected for good survival and rapid growth when cultured in cages suspended in upstate New York farm

ponds. Before being used in the study, fish were transferred to Wet Laboratory I (48 m^2) and acclimatized for 15 weeks to single-pass systems and Purina Trout Chow #5 (use of a trade name does not constitute an endorsement).

Wet Laboratory Condition

Village of Brockport tap water was used (Lake Ontario; pH, 7.78-7.92; alkalinity, 89-97 mg/L $CaCO_3$; Richard Preston, Brockport Waterworks, personal communication). Throughout the nine week study ambient room temperature was maintained at 23-26 ^{o}C. Both Wet Laboratories I and II lack windows; photoperiod was controlled mechanically and illumination was by incandescent light.

Experimental Setup

The study was conducted with twelve reuse systems in Wet Laboratory II (128 m^2). Each reuse system included a fish holding unit (245 x 61 x 27 cm, 400 L) and a biofilter/system settling basin (61 x 61 x 61 cm, 200 L), both constructed of stainless steel (Fig. 1). Limestone (2-7 cm) was used as the filter media. It provided a suitable surface for bacterial growth and a reservoir of $CaCO_3$, which helped to maintain alkalinity and pH at

acceptable levels. A 1/40 hp submersible pump was installed at the bottom of the biofilter and circulated water at 11-30 Lpm from the biological filter through 1.0 cm PVC tubing to the fish holding unit. Water flowed by gravity from the fish holding unit to the biological filter. The total volume of water was exchanged once every 13-36 minutes.

Culture units used in the study were maintained 99 % of the time at 16, 22, 28 and 34 ^{o}C $\pm$ 2 ^{o}C (Fig. 2-5) and 98 % of the time above 4.0 mg/L O^2 or 60 % saturation (Fig. 6-9). Exceptions occurred when the ventilation and electricity were turned off (day 33) and when fish holding tanks were flushed (days 24, 33, 41 and 50). Culture temperatures (16, 22, 28 and 34 ^{o}C) bracketed the documented optimal range for channel catfish and brown bullhead. Culture temperatures also approximate the lower and upper temperature for initiation of growth and thermal stress, respectively, observed for black bullhead in cages (Buttner, Department of Biological Sciences, SUNY College at Brockport, personal communication).

Each test condition (16, 22, 28 and 34 ^{o}C) was run in triplicate. Systems maintained at 28 and 34 ^{o}C had their own biological filters and heating systems. Systems maintained at 16 and 22 ^{o}C shared a common biological filter and cooling system. At 22 ^{o}C, cooling

was provided by a bath-model 2095 by Forma Scientific, Ohio. At 16 ^{o}C, a living stream-model LS 700 by Frigid Units Inc., Ohio was initially used. The unit broke down on day 37 and was replaced with a bath-model 2095 (Forma Scientific). Twenty-six heaters were used in this study: 2 heaters for each replicate in the 28 ^{o}C treatments and 6-7 heaters for each replicate in the 34 ^{o}C treatments.

Continuous illumination (< 10 Lux at tank level) was provided by two soft white light bulbs (40 watts), one located in front and a second behind the reuse system (Table 1). Two PVC tubes (diameter 8 cm; 33-41 cm long) were placed into each fish holding unit. The tubes were placed side-to-side, with the lumen open to water flow. The reduced lighting and addition of tubes, as hiding places for fish, reduced stress experienced by fish during the study. To facilitate feeding and collection of uneaten food, a plastic mesh (56 cm on each side, 13 cm deep) was installed in each tank. The plastic squares were submerged 11 cm in the water and encircled the PVC tubes. They prevented food from drifting away and being discharged. Both PVC tubes and plastic squares were located opposite the water inflow.

Water was discharged from the fish holding unit to the biological filter by two gravitational methods. In the "flow-in" method, a tube returned water underneath the limestone (Tanks 16A-C; 22A-C; 28B; 34A and 34C). In

the "splash-in" method, the discharge tube terminated above the biofilter and water splashed into the limestone and agitated water to increase DO (Tanks 28A and 28C; 34B).

Fish Stocking

On 11 August 1989, 416 black bullhead fingerlings were transferred from Wet Laboratory I to reuse systems in Wet Laboratory II. Each reuse system received 33-37 fingerlings that averaged 10-13 cm total length (TL) and 6-20 g each (Table 4). Fish were acclimated to the new experimental temperature over 45 minutes. Since several weeks are typically required for fish to acclimate completely to a new condition (Brett 1979), the fingerlings were maintained for 34 days in their respective reuse systems (16, 22, 28, and 34 ^{o}C) before the formal study was initiated. During this 34 day period, fish were fed daily to satiation with the Trout Chow ration. Thirty-three fish died during the acclimation period (6 at 16 ^{o}C, 17 at 22 ^{o}C; 2 at 28 ^{o}C and 8 at 34 ^{o}C). Dead fish were replaced with new, similarly-sized fish. Because of the relatively high mortality in systems maintained at 22 ^{o}C, they were flushed totally on 13 September 1989. The formal study was initiated on 14 September 1989.

Water Quality Monitoring Regime

Throughout the nine week study, water quality parameters were monitored at a standard time and by standard procedures (Table 2). Dissolved oxygen (DO) was measured once each day before 1200 or after 2100, except on day 29 and 61 when the monitoring equipment was being used in the field. Temperature of each reuse system and room temperature were recorded twice daily, between 0800-0900 and 1700-1800. If neccessary, water and room temperature were adjusted. Total ammonia-nitrogen (TAN), nitrate-nitrogen, nitrite-nitrogen, alkalinity and pH were monitored once each week, before 1700 or after 2200. If water quality deteriorated the system was flushed and/or provided supplemental aeration. Initially only one small aerator was available and it was used in units where DO was less than 4.0 mg/L or nitrite-nitrogen exceeded 0.1 mg/L (28 and 34 ^{o}C treatments; Fig. 8-11). Starting day 43, supplemental aeration was provided continuously to all units.

Fish Monitoring

Fish in all treatments were observed daily. Dead fish were removed, and their length and weight recorded. Fish with fungus, dropsy and necrotic fin areas were assessed as unhealthy and removed from the systems.

General fish behavior (agonistic behavior such as biting, chasing) and condition were documented. Dead fish were taken out as soon as observed; however, this was difficult for the 22 and 34 ^{o}C treatments. The 22 ^{o}C treatment units were located above the 28 ^{o}C treatment units, so it was hard to check them without excessively disturbing fish at the 28 ^{o}C treatments. In the 34 ^{o}C treatments dead fish decomposed rapidly due to the higher temperature.

Wet weight of black bullhead was determined by a sample of 10-20 fish weighed to the nearest 0.1 g on day 1 and day 14. Total wet weight of fish was taken on day 43 and at harvest (day 65).

Daily Operation

Black bullheads were fed to excess with a known weight of food once each day. Fish were fed between 1800 and 2000. Food pellets not consumed after 2 hours were collected and counted. The two hour feeding period was selected since over 90 % of the pellets remained intact when tested at 28 and 34 ^{o}C for more than two hours, and to provide ample time for the fish to eat. Average weight of each pellet (0.081 g) was determined by weighing three batches of 50 pellets. Total weight of food ingested was determined by subtracting the computed

weight of uneaten pellets (0.081 g x number of pellets removed) from the weight of feed originally presented.

To facilitate pellet collection and to maintain a healthy culture environment, culture units were siphoned as needed between 0900-1200 for the 28 and 34 °C treatments and in the evening, after collection and enumeration of all food pellets at 2200, for the 16 and 22 °C treatments.

Routine Maintenance

Make-up water for evaporative loss, and water removed by siphoning (to remove feces and uneaten food) was added once every two weeks for the 16, 22, and 28 °C treatments. Make-up water was added as needed and only in quantities that would not alter the water temperature more than 2 °C of the controlled temperature of the treatment. For the 34 °C treatment make-up water was added every four-five days, except for tank 34B which developed a minor leak during week 6 and required additional water every two days. Biofilters of the 22, 28, and 34 °C treatments were flushed twice to remove particulates and maintained biofilter function (22 °C on days 23, 40; 28 and 34 °C on days 33, 50). Again, water was added in quantities that would not alter the water temperature more than 2 °C of the controlled temperature

of the treatment, except for 28 and 34 °C treatments on day 33. The 16 °C treatments were never flushed.

Harvest

After nine weeks all fish were harvested and the study terminated. Survival and total weight of fish for each treatment were determined. For each reuse system the average weight of fish (total weight of fish/number of fish), amount of food ingested, and feed conversion were calculated. Feed conversion (C) was modified from Boyd (1988) and Jensen (1988):

$$\text{Feed conversion ratio (C)} = \frac{\text{Amount of Feed (g)}}{\text{Avg. Weight Gain of Fish (g)}}$$

STATISTICAL ANALYSES

Effects of water temperature on fish survival and growth, amount of food ingested, and feed conversion ratio were tested for significance at the 95% confidence level (P=0.05 level; Bazigos 1974). The null hypothesis was:

'Temperature has no effect on fish survival, growth, and feed conversion'.

Point-5 was used to compute one-way ANOVA of water quality parameters and to make graphic models (Keppel 1982; Kirk 1982). Water quality parameters were tested with F-test and if they differed significantly with a Tukey-test. Lotus 1-2-3 and Harvard Presentation Graphics were used to make the final graphics. Bargraphs and linegraphs were employed to describe growth as a function of food consumption and temperature fluctuation (modified from Wurtsbaugh and Cech 1983).

RESULTS AND DISCUSSION

Culture Environment

Water quality in all culture units remained 93-100 % of the time within ranges generally considered acceptable for fish culture, except TAN as NH_3 frequently exceeded recommended levels for pond and single-pass fish culture (Boyd 1988; Thurston et al. 1979; Wellborn 1987).

Temperature: Temperatures for replicates within the 22, 28, and 34 ^{o}C treatments remained 99 % of the time within 2 ^{o}C of the desired temperature and did not differ significantly from each other ($P>0.05$; F-Test; Table 3; Fig. 2-5). In the 16 ^{o}C treatment, there was a significant difference between the replicates that was confirmed by a Tukey-test ($P<0.05$; Table 3; Fig. 2).

Several events complicated temperature control of the 16 °C treatment including (1) an electrical shut down from 0830-0845 on 7 October 1989 (day 24); (2) loss of laboratory ventilation from 0700-2300, between 7-10 October 1989 (days 24-27), because the hall was being painted to honor the visiting day of the NY Governor; and (3) failure of the Frigid Unit's chiller, living stream-model LS 700, on 11 October 1989 (day 28), which could not be repaired immediately. The replacement unit, a Forma Scientific bath-model 2095, took 6 days to calibrate, and it was not until 18 October 1989 (day 35) that the temperature dropped to less than 17 °C (Fig. 2). F-test analyses indicated that before the original cooling unit broke down and during the transition period (days 1-35), no statistically significant differences existed between the replicates ($P<0.05$; F-Test; Fig. 2). However, between days 36-65 Tank C was significantly warmer than Tanks A and B ($P<0.05$; F-Test; Tukey-test; Fig. 2). It appears that the small chiller which lacked an impeller agitator could not cool and mix the water as effectively as the large chiller.

Although there was a statistical difference between replicates at 16 °C (between Tanks A and B vs. Tank C) for approximately 30 days, the replicates were still grouped together as a unit for other analyses. This was done because the absolute difference between tanks within

the treatment was usually less than 1 ^{o}C, vs 3-6 ^{o}C when compared to temperatures for tanks at the 22 ^{o}C treatment. Also, the significant difference existed for less than half of the study mean (days 36-65). Finally, fish responses (survival, growth and feed conversion) were similar in the three replicates.

Finer control of temperature in all units was complicated by changes in ambient temperature outside the laboratory, flushing of the 22 ^{o}C treatment on days 23 and 40 and of treatments 28 and 34 ^{o}C on days 33 and 50; and the periodic addition of make-up water to all units (Wheaton 1985; Figures 2-5).

Dissolved Oxygen (DO): DO was significantly different between replicates in all treatments ($P<0.05$; F-Test; Table 3; Figures 6-11). The 16 ^{o}C treatment initially used a Frigid Units chiller model LS 700 with an impeller to cool and circulate water. On day 28 this unit broke down and was replaced with a smaller cooling unit (Forma Scientific model 2095) that lacked an impeller. DO in the units decreased (particularly in Tank C) and the variation between replicates increased (Fig. 6).

DO level in all treatments was affected by the "splash-in" and "flow-in" discharge from the fish holding unit to the biological filter (Fig. 1, 6-11). Tanks 28B, 34A and 34C used the "flow-in", while Tanks 28A, 28C and

34B used the "splash-in". All replicates in the 16 and 22 ^{o}C treatments used the "flow-in" method. Tanks with the "splash-in" method had higher levels of DO (Fig. 8-11).

The minimally desirable DO concentration (5 mg/L) per fish culture was hard to maintain in the 28 and 34 ^{o}C treatments (Fig. 8-11; Boyd 1988; Thurston et al. 1979), because fish gained considerable weight and because of the low solubility of DO in warm water (Wheaton 1985). On day 40, the DO level in treatment 28 ^{o}C dropped to less than 4.0 mg/L or 60 % saturation. On all other days for all treatments DO remained above 4.0 mg/L or 60 % saturation. Continuous supplemental aeration was subsequently applied to all units and no further incidents of critically low DO were observed.

Other Water Quality Parameters: All other monitored water quality parameters (nitrite-nitrogen, nitrate-nitrogen, pH and alkalinity) remained at ranges considered acceptable for good survival and growth of fishes, except total ammonia-nitrogen as NH_3 was higher during the initial water quality tests, but exhibited a gradual decrease over time (Fig. 12-15; Boyd 1988; Thurston et al. 1979; Wellborn 1987). There were no statistically significant differences between replicates for total ammonia-nitrogen, nitrite-nitrogen, and

nitrate-nitrogen ($P>0.05$; F-test; Table 3; Fig. 12-31). The relatively low levels of total ammonia-nitrogen and nitrite-nitrogen, and the general increase in nitrate-nitrogen in all systems indicate that the biological filters were functioning properly.

Alkalinity was not significantly different for replicates within each treatment ($P<0.05$; F-Test; Table 3; Fig. 24-27). Alkalinity was similar in all treatments and tended to decrease over time, except after systems were flushed (especially week V; 28 and 34 ^{o}C). Interestingly, flushing on day 33 raised alkalinity in the 28 ^{o}C treatment, but lowered it in the 34 ^{o}C treatment (Fig. 26, 27). Throughout much of the study the 34 ^{o}C treatment had slightly higher alkalinity, and exhibited a gradual increase over time vs a gradual decline of alkalinity in all other treatments. Perhaps the higher temperature increased the solubility of $CaCO_3$ or promoted evaporation. Make-up water used in the study originated from Lake Ontario with a typical alkalinity of 89-97 mg/L $CaCO_3$.

Replicates of the 16, 22 and 28 ^{o}C treatments did not differ significantly in pH ($P>0.05$; F-test; Table 3; Fig. 28-31). For the 34 ^{o}C treatment, pH in Tanks 34A and 34C were significantly different from that in Tank 34B ($P<0.05$; F-Test; Tukey-Test; Table 3; Fig. 31). Tank 34B started to leak during week 6 and required more

frequent additions of make-up water, which may have resulted in the observed differences throughout the study.

Biological Data

Food ingested in 22, 28 and 34 ^{o}C treatment was approximately 0.6 g/g fish harvested, but only fish at 28 ^{o}C grew well. Food ingested in 16 ^{o}C treatment was only 0.3 g/g fish harvested, but fish still grew.

Feeding Behavior: Black bullhead naturally prefer deep and quiet water; they are usually found near structure. (Scott and Crossman 1973; McLarney 1984). In nature, black bullhead normally display "social appetite"; they remain in compact schools with individual fish actually touching each other. Breakdown of this schooling instinct indicates that fish are stressed (Bowen 1931; Darnell and Meirotto 1965). PVC tubes were placed in each holding unit to provide hiding places for the fish and to encourage "social appetite".

"Social appetite", exhibited as bunching and aggregation behavior, was normally observed in the 22 and 28 ^{o}C treatments. Fish normally aggregated inside the PVC tubes and only came out when food was introduced. "Hunger drive" and "social appetite" usually increase feeding rate (Bowen 1931; Darnell and Meirotto 1965).

Fish in the 16 and 34 °C treatment did not exhibit "social appetite" (e.g. hiding, aggregate), and remained dispersed outside the tube.

In the 34 °C treatment, about 50 % of the fish exhibited agonistic behavior (e.g. biting, chasing; Parker and Davis 1979) and individual fish swam around listlessly. Most fish moved around the heater and just under the surface; some fish remained still on the PVC tubes. Fish at 34 °C did, however, feed vigorously.

In the 16 °C treatment, about 40 % of the fish remained stationary on the bottom; either beside or inside the PVC tubes. Fish did not aggregate and settled listlessly. Black bullhead at 16 °C ate little and rarely moved. It appears that the metabolic rate in black bullhead was substantially reduced (apneic) and the fish experienced anorexia (loss of appetite), as has been observed for brown bullhead below 16-20 °C (Swingle 1957; Crawshaw 1984).

Survival: Survival in 16, 22 and 28 °C treatments was similar and exceeded 80 %; in the 34 °C treatment survival was only 59 %. The best survival occurred at the 28 °C treatment (Table 4; Fig. 33, 34).

All mortalities from the 16, 22 and 28 °C treatments had cotton-like growths on their bodies, which could be the fungus Saprolegniasis. Dead and dying fish from the

34 °C treatment frequently exhibited fin necrosis; a few had dropsy. Sometimes dead and dying fish had lost not only their caudal fin, but also considerable muscle tissue at caudal peduncle, thereby leaving vertebrae exposed (Peduncle disease; Post 1987). These pathological conditions are commonly caused by opportunistic pathogens normally found in surface water. The diseases are stress mediated and typically infect fish only when stressed; however, they can also be caused by dietary deficiency (Parker and Davis 1979; Post 1987). According to Scott and Crossman (1973) 34 °C is very near to the lethal temperature for black bullhead.

Growth: Fish gained weight in all treatments, and growth appeared linear at 22 and 28 °C treatment. The best growth occurred in the 28 °C treatment. Doubling time for fish at 28 °C treatment was approximately every 54 days (Fig. 32, 35).

Fish in the 16 and 34 °C treatments exhibited little growth. In the 16 °C treatment, fish apparently lost weight after the second and third weighing (Fig. 32). Since only a portion of the population was weighed the first and the second times, it is possible that sampling bias had caused the apparent weight loss.

A second concern for fish at 16 °C treatment was their relatively low start weight 6-9 g (vs 12-20 g for

other treatments, Table 4). To determine if fish at 16 °C treatment could physically ingest the trout chow pellet, 16 fish (6-9 g) were placed into each of two reuse systems maintained at 22 °C. Between 6-26 December 1989 their average weight increased by 56 % and 34 %, respectively. Only one mortality was observed for a 97 % survival. Data indicate that the reduced growth of fish in the 16 °C treatment was temperature induced and not caused by their initial body size or weight.

Food Ingested and Feed Conversion: The average amount of food (g) ingested per fish harvested (g) was similar for the 22, 28 and 34 °C treatments (Fig. 36). The best feed conversion (C) was observed for fish at 28 °C treatment (Table 4; Fig. 36-40; Stickney 1979). Lower growth, but high feed conversions, were observed in the 22 and 34 °C treatments (Table 4; Table 5; Fig. 35-37).

Black bullhead at 16 °C ingested a limited amount of food, but feed conversion was good (Table 4; Table 5; Fig. 35-37). At 34 °C, black bullhead ingested similar amounts of food as in 22 and 28 °C, but feed conversion was poor (perhaps reflective of increased metabolic activities to compensate for thermal stress). In some cases, feed conversion was negative in replicates of the 34 °C treatment, perhaps because some fish lost their

caudal and peduncle due to peduncle disease (Table 4; Table 5; Fig. 33, 37).

Acute stress after handling and weighing fish can inhibit appetite and feeding (Fig. 38-40; Knights 1985). A typical recovery period for 22 and 28 ^{o}C treatment was about seven days. Even after seven days, feeding rates did not return to pre-handling levels. At 16 ^{o}C fish ingested less food and it was difficult to distinguish when the fish returned to their normal low rate of ingestion. The recovery period for fish at 34 ^{o}C was three-four days.

CONCLUSIONS AND IMPLICATIONS

Under conditions employed in Wet Laboratory II three conclusions are evident:

1. The best survival, growth, feeding activity and feed conversion were observed for black bullhead maintained at 28 ^{o}C. Data indicates that 28 ^{o}C was near the optimal temperature for black bullhead.
2. Black bullhead maintained at 16 ^{o}C exhibited good survival and converted food efficiently, but the amount of food ingested was low and growth was limited. Fish demonstrated behavioral modification and remained inactive most of the time.

3. Survival, growth and feed conversion of black bullhead at 34 °C were reduced, though the amount of food ingested (g food/g fish harvested) approximated that of fish maintained at 22 and 28 °C. Fish at 34 °C demonstrated behavioral modification, continuously swam in a listless manner, and experienced disease problems.

These findings have aquaculture implications. Farmers who culture black bullhead should feed fish at 16 °C. As water temperature increases, fish will ingest more food and convert more efficiently. If surface temperature gets too warm (e.g., approaches 34 °C) fish will become stressed (poor feed conversion, mortalities occur). Under warm water conditions it may be desirable to circulate cool, deep water or to relocate cages to a shaded, cooler area.

Additional suggestions include: multiple daily feedings and reduction of light by use of a cover over the cage or with a tube placed on the bottom of a cage. Cages should not be located in open water with full sunlight.

For more detailed recommendations, the study should be repeated with narrowed temperature ranges (23-30 °C) to clarify more precisely the optimal growth condition for black bullhead. Photoperiod and multiple feedings

are interesting factors that should be studied to determine how they affect black bullhead growth.

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Table 1. Intensity of continuous illumination at the front, middle and back of culture units in Wet Laboratory II during the nine week experiment.

	Sample Size	Lux		
		Mean	S.D	Range
Front	12	0.9	0.5	0.4-1.9
Middle	12	0.9	0.4	0.4-1.9
Back	12	3.5	2.5	0.6-8.4

Table 2. Methodologies used to monitor water quality in black bullhead culture units in Wet Laboratory II at SUNY College at Brockport.

Parameter	Analytical Procedure	Reference
Alkalinity (mg/L as $CaCO_3$)	Titrimetric	APHA 1989
Dissolved Oxygen (mg/L)	Polarographic Meter, YSI Model 58, with Winkler Calibration	APHA 1989
pH	pH Meter, Model SA 250	APHA 1989
Temperature	pH Meter, Model SA 250	APHA 1989
Nitrate-Nitrogen (mg/L)	Cadmium Reduction	Hach 1985
Nitrite-Nitrogen (mg/L)	Diazotization	Hach 1985
Total Ammonia-Nitrogen* (mg/L)	Nesslerization	Hach 1985

* To convert Total Ammonia-Nitrogen (TAN) to Unionized Ammonia, TAN value must be multiplied with 1.22 (Hach 1985) than multiplied it again by a percentage corresponding to the relevant temperature and pH (Piper et al. 1986)

Table 3. Water quality parameters in culture units used to maintain black bullhead for nine weeks at 16, 22, 28 and 34 °C. Significant differences between water quality parameters among replicates ($P<0.05$; F-test and Tukey-test) are indicated with an arterisk (*).

Parameter	Temperature (°C)	Sample size	Mean	Range
Total Ammonia-Nitrogen (mg/L)	16	27	0.3	0.2-0.4
	22	27	0.4	0.3-0.5
	28	27	0.4	0.3-0.6
	34	27	0.4	0.3-0.5
Nitrite-Nitrogen (mg/L)	16	27	0.0	0.0-0.0
	22	27	0.0	0.0-0.1
	28	27	0.1	0.0-0.2
	34	27	0.0	0.0-0.1
Nitrate-Nitrogen (mg/L)	16	27	4.6	2.5-7.0
	22	27	5.1	2.2-7.9
	28	27	9.5	4.4-15.1
	34	27	7.3	4.1-12.0
Alkalinity (mg/L as $CaCO_3$)	16	27	77.0	73-84
	22	27	80.0	72-93
	28	27	69.0	55-82
	34	27	118.0	98-140
pH	16	27	8.1	7.9-8.2
	22	27	7.9	7.8-8.0
	28	27	7.7	7.4-7.8
	34	27	8.1	7.8-8.4*
Dissolved Oxygen (mg/L)	16	174	9.6	8.5-11.2*
	22	174	7.7	6.6-9.6 *
	28	174	5.8	3.1-7.1 *
	34	174	5.7	4.2-7.1 *
Temperature (°C)	16	195	16.3	15.0-18.4*
	22	195	21.7	20.7-23.3
	28	195	27.8	22.9-28.9
	34	195	33.6	28.3-35.5

Table 4. Stock and harvest data for black bullhead cultured at 16, 22, 28 and 34 °C for nine weeks. Conditions were run in triplicate with 33 to 37 fish/replicate. Reported values are mean and (SD).

Test Condition	Stock		Harvest				
	No.	Mean Weight (g)	No.	Mean Weight (g)	Survival %	Growth %	C
16	106	7.0	92	8.4	86.6	22.3	1.4
S.D		(2.2)		(2.0)	(12.0)	(10.4)	(0.6)
22	103	12.2	83	17.1	80.7	43.4	4.6
S.D		(2.1)		(2.3)	(6.8)	(33.8)	(5.9)
28	105	18.5	95	41.7	90.5	124.5	1.1
S.D		(2.1)		(7.2)	(1.6)	(26.0)	(0.2)
34	102	13.7	60	17.3	59.0	29.8	3.0
S.D		(3.7)		(4.5)	(9.3)	(38.6)	(8.9)

Table 5. Food ingested by black bullhead during the nine week study.

Test	Fish Number		Fish Weight		Food Ingested	
	Stock	Harvest	Stock (g)	Harvest (g)	Total (g)	g/g of Harvested Fish
16A	37	33	6.1	7.3	61.4	0.25
16B	35	34	5.3	6.6	63.2	0.28
16C	34	25	9.5	8.7	68.2	0.31
22A	35	26	11.6	21.8	313.0	0.55
22B	35	28	10.5	17.3	280.0	0.58
22C	33	29	14.6	16.1	296.9	0.63
28A	35	31	18.2	48.7	891.4	0.59
28B	35	32	20.7	47.3	917.9	0.61
28C	35	32	16.6	34.9	693.7	0.62
34A	35	19	10.7	16.4	194.7	0.62
34B	34	18	17.8	20.2	193.0	0.53
34C	33	23	12.6	25.0	395.3	0.69

Figure 1. Diagram of reuse system used to maintain black bullheads for nine weeks at 16, 22, 28 and 34 °C in Wet Laboratory II at SUNY College at Brockport.

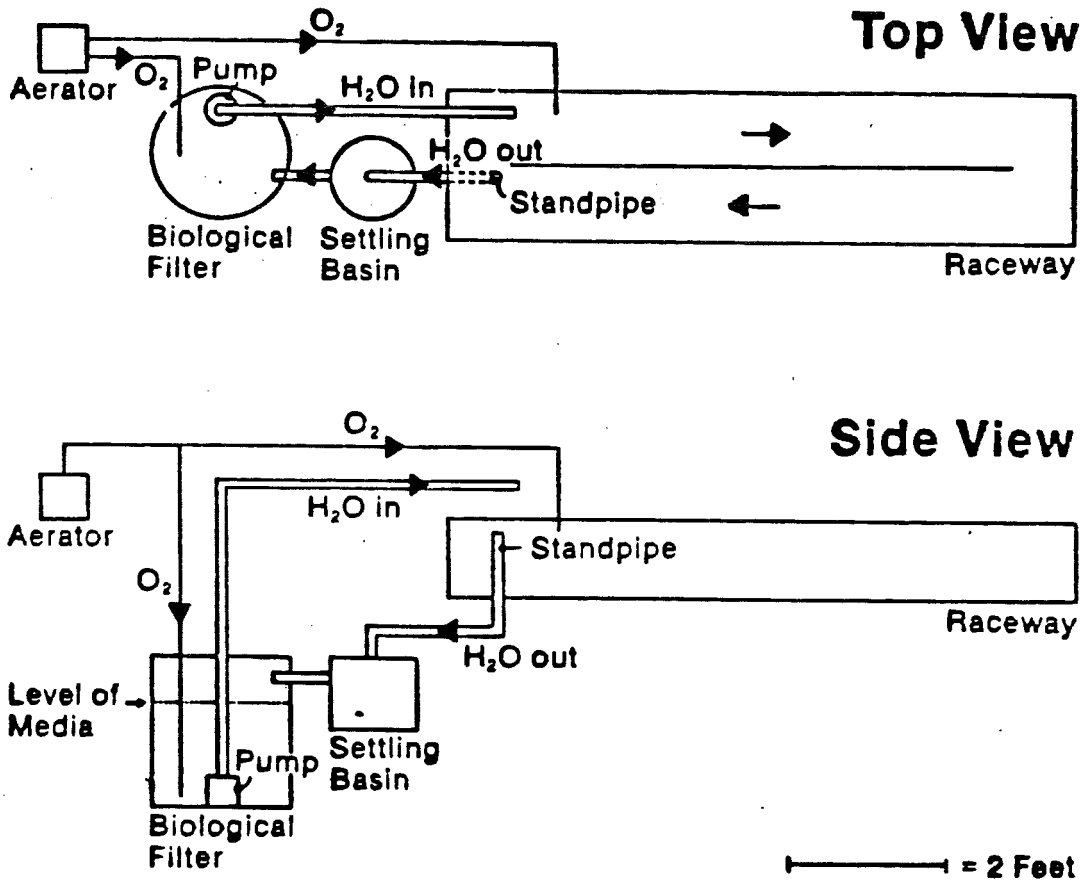

Figure 2. Temperatures for replicates A, B, and C at 16 °C.

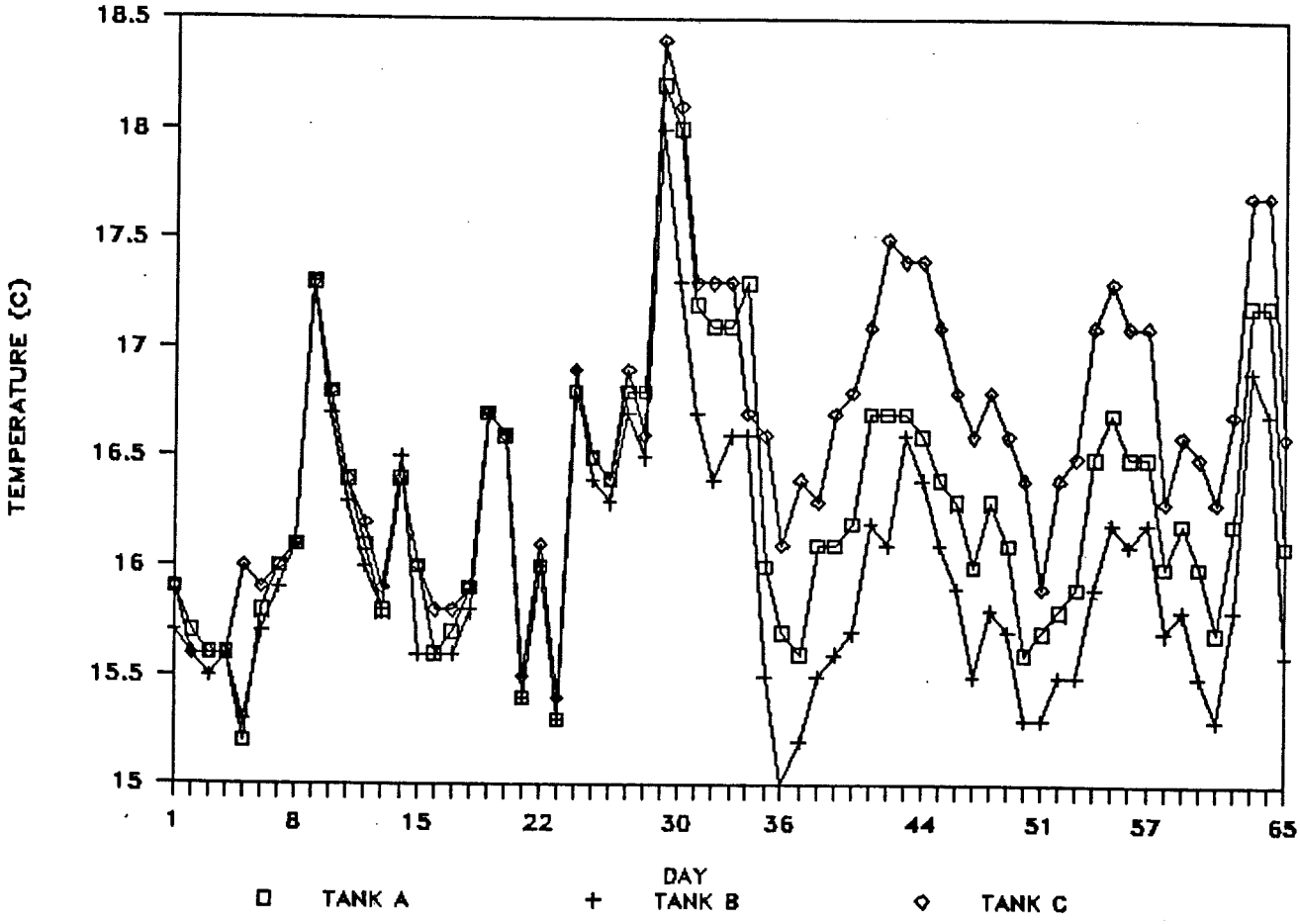

Figure 3. Temperatures for replicates A, B, and C at 22 °C.

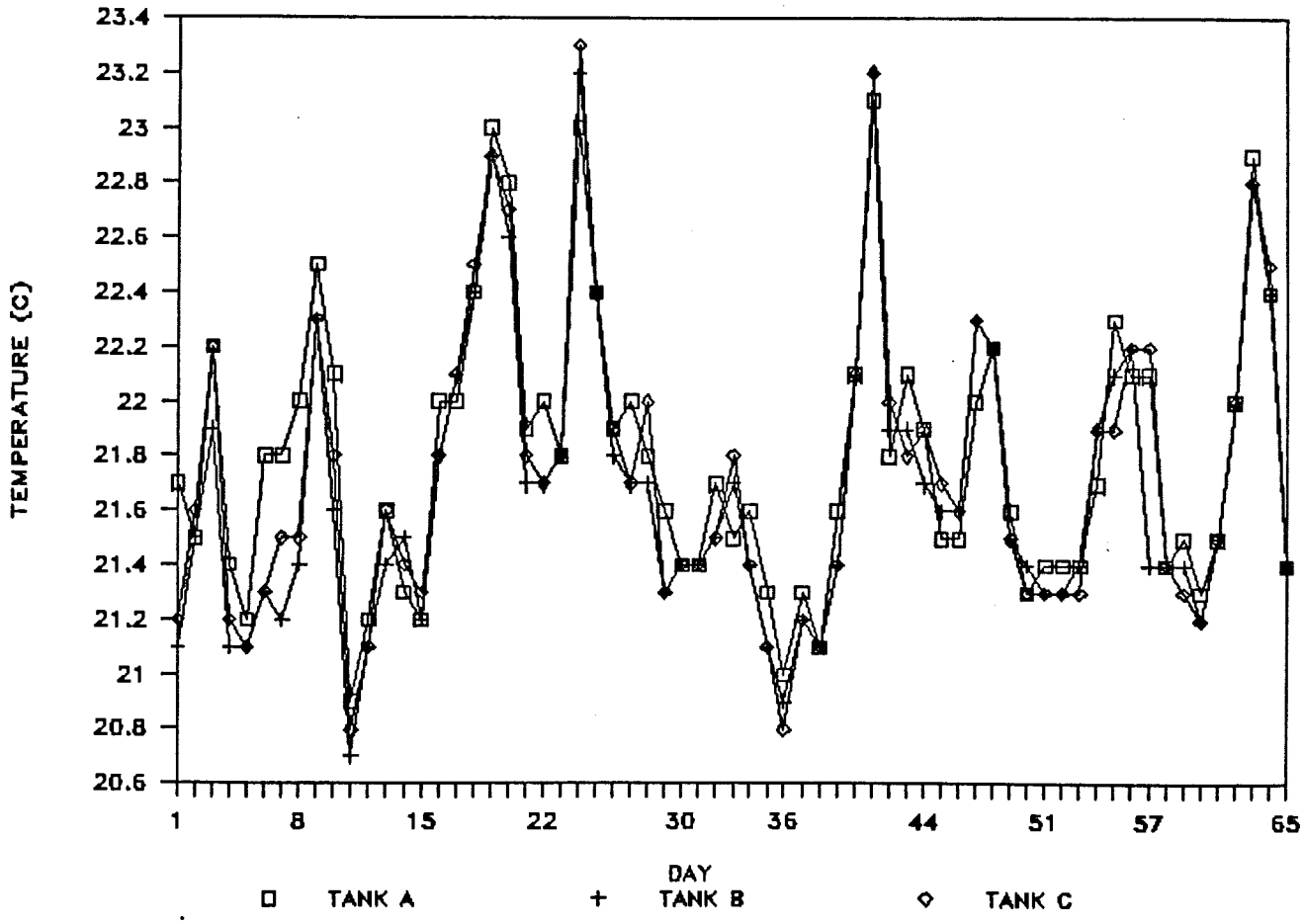

Figure 4. Temperatures for replicates A, B, and C at 28 °C.

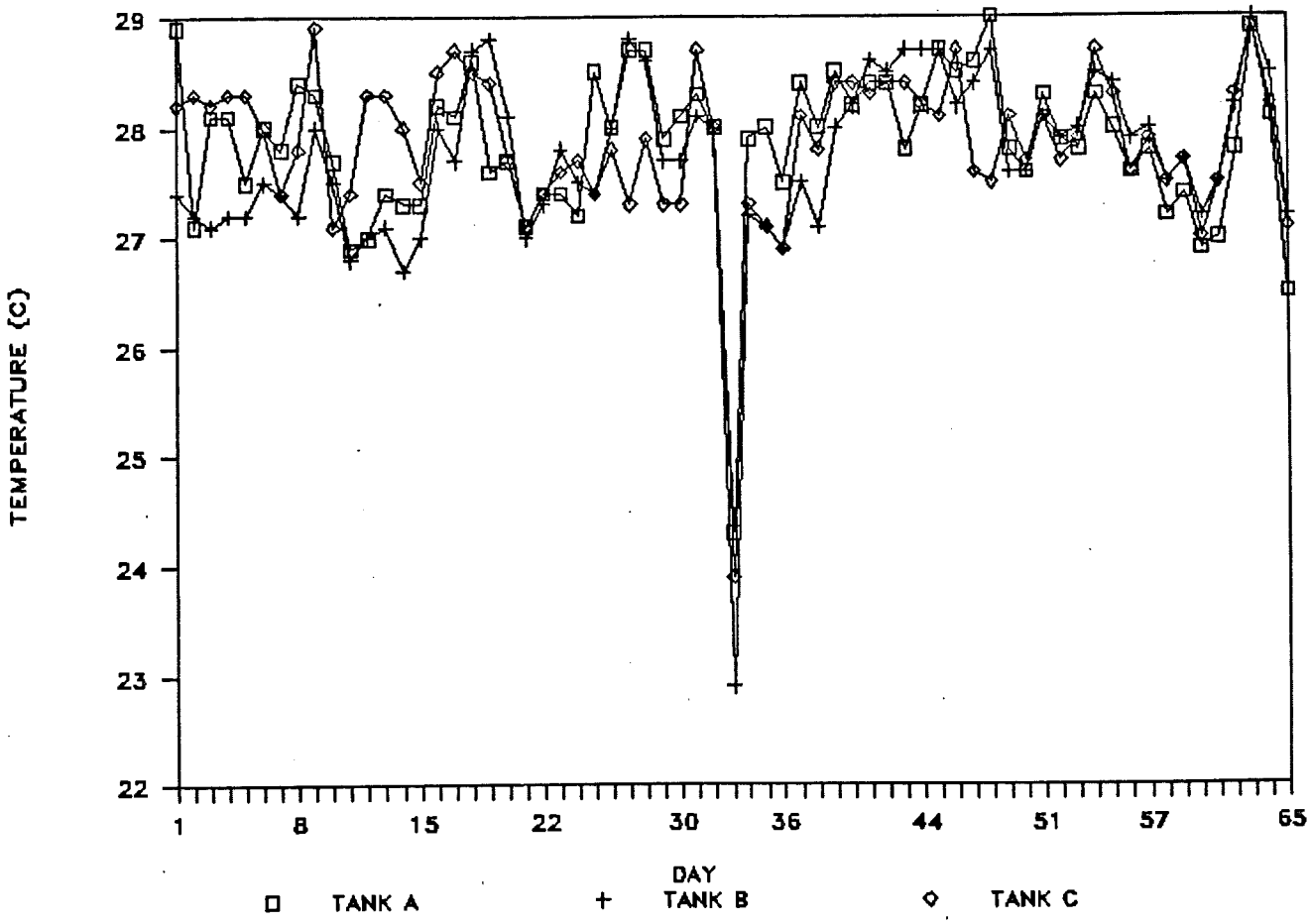

Figure 5. Temperatures for replicates A, B, and C at 34 °C.

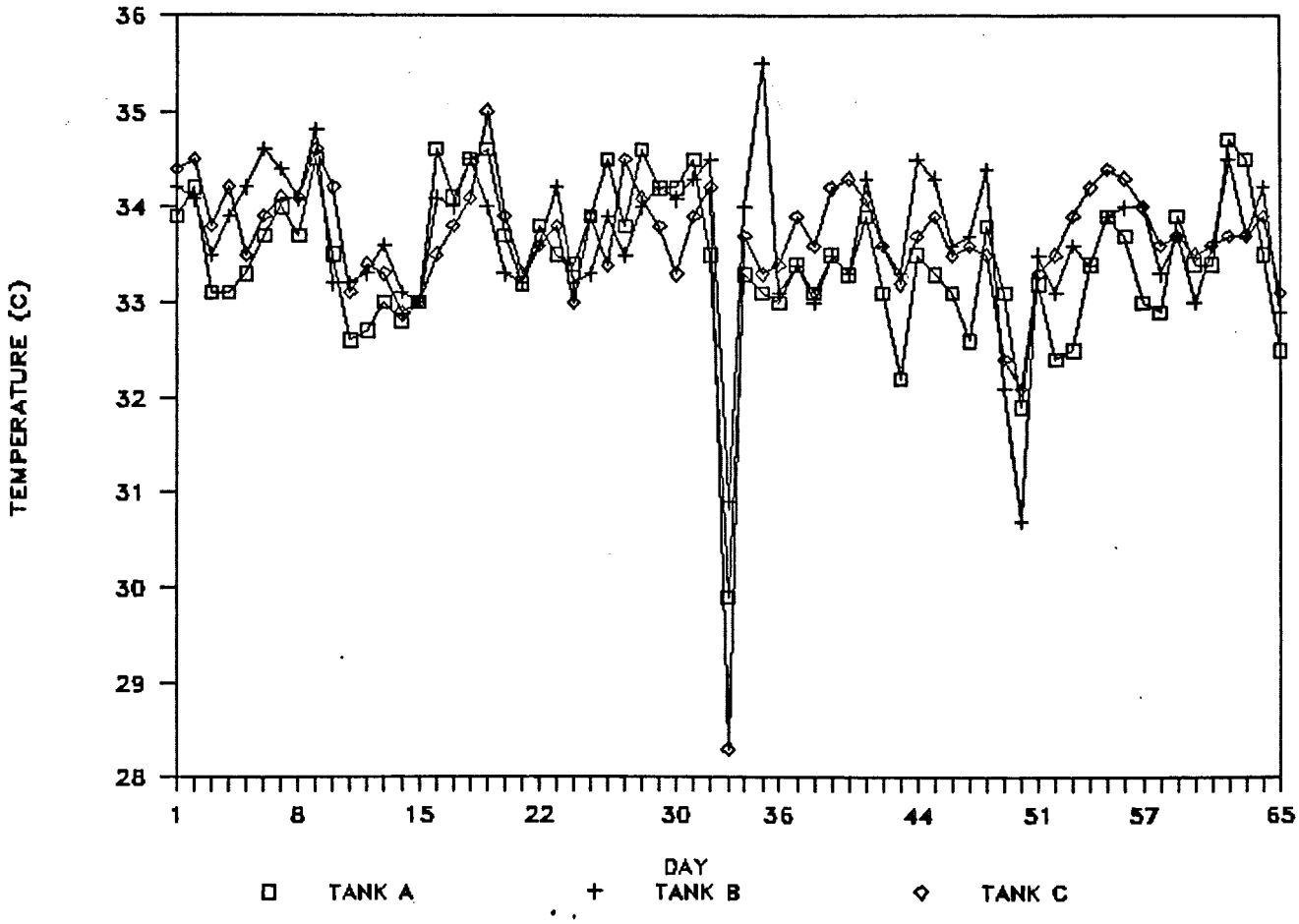

Figure 6. Dissolved Oxygen (DO) for replicates A, B, and C at 16 °C.

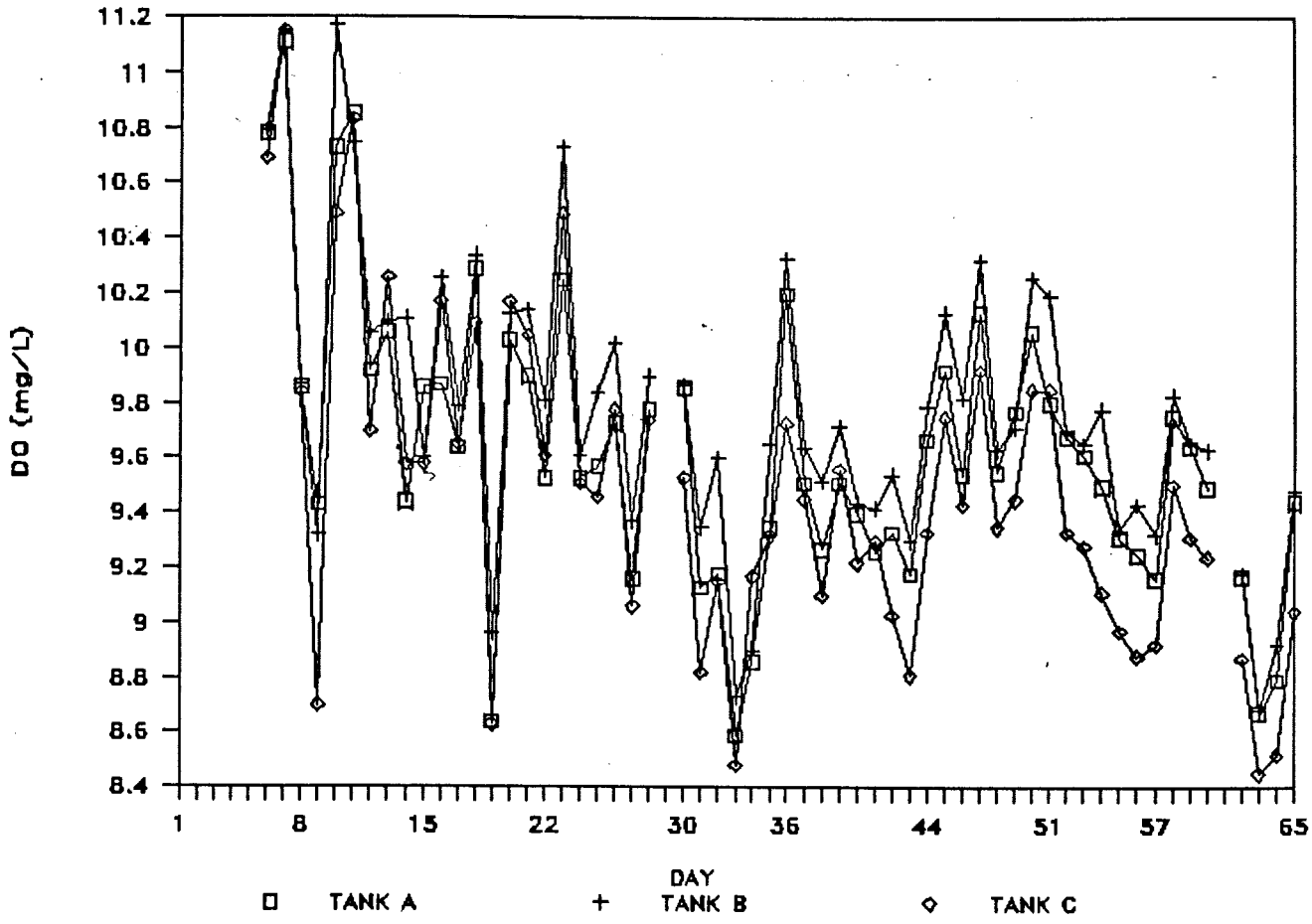

Figure 7. Dissolved Oxygen (DO) for replicates A, B, and C at 22 °C.

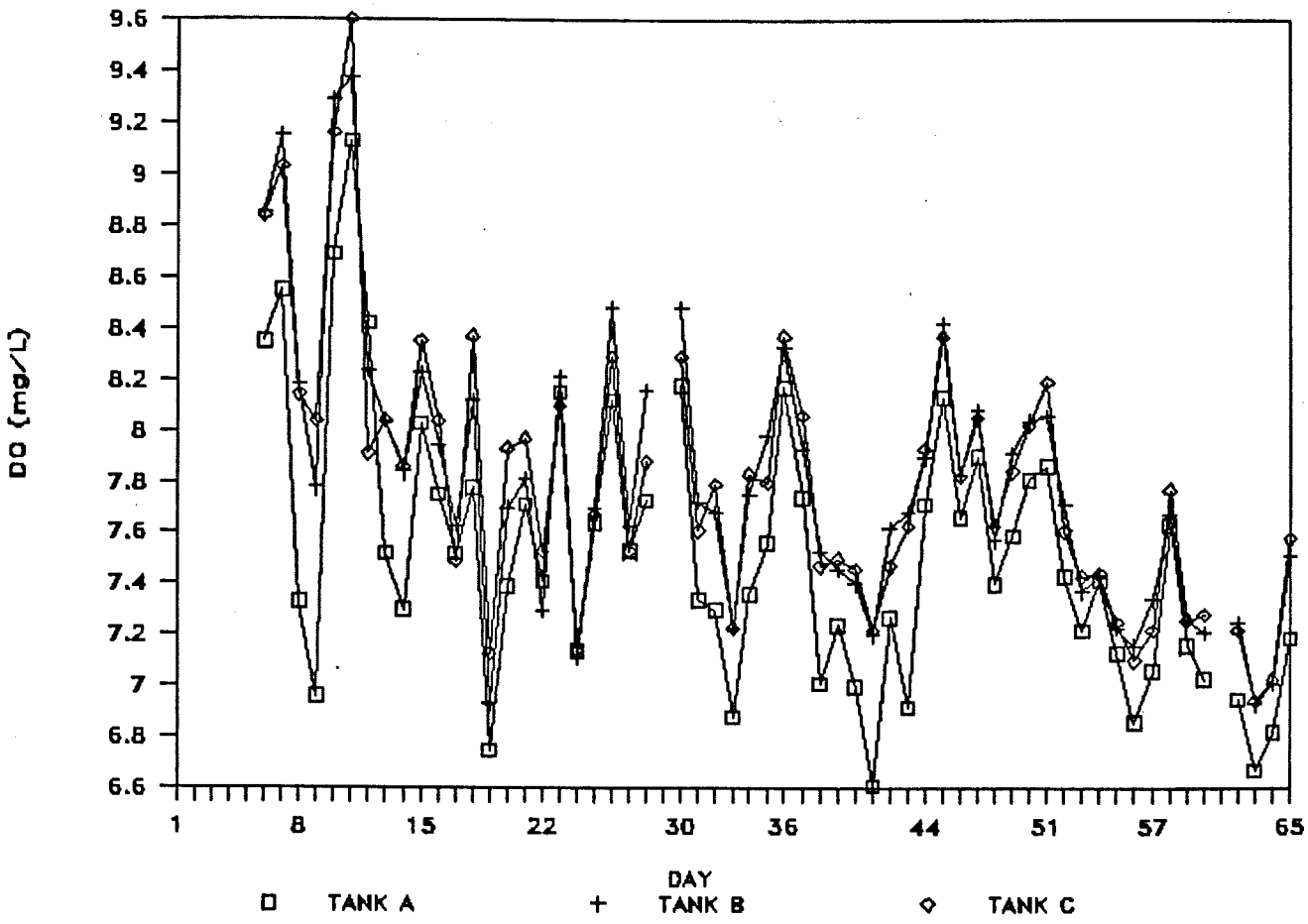

Figure 8. Dissolved Oxygen (DO) for replicates A, B, and C at 28 °C.

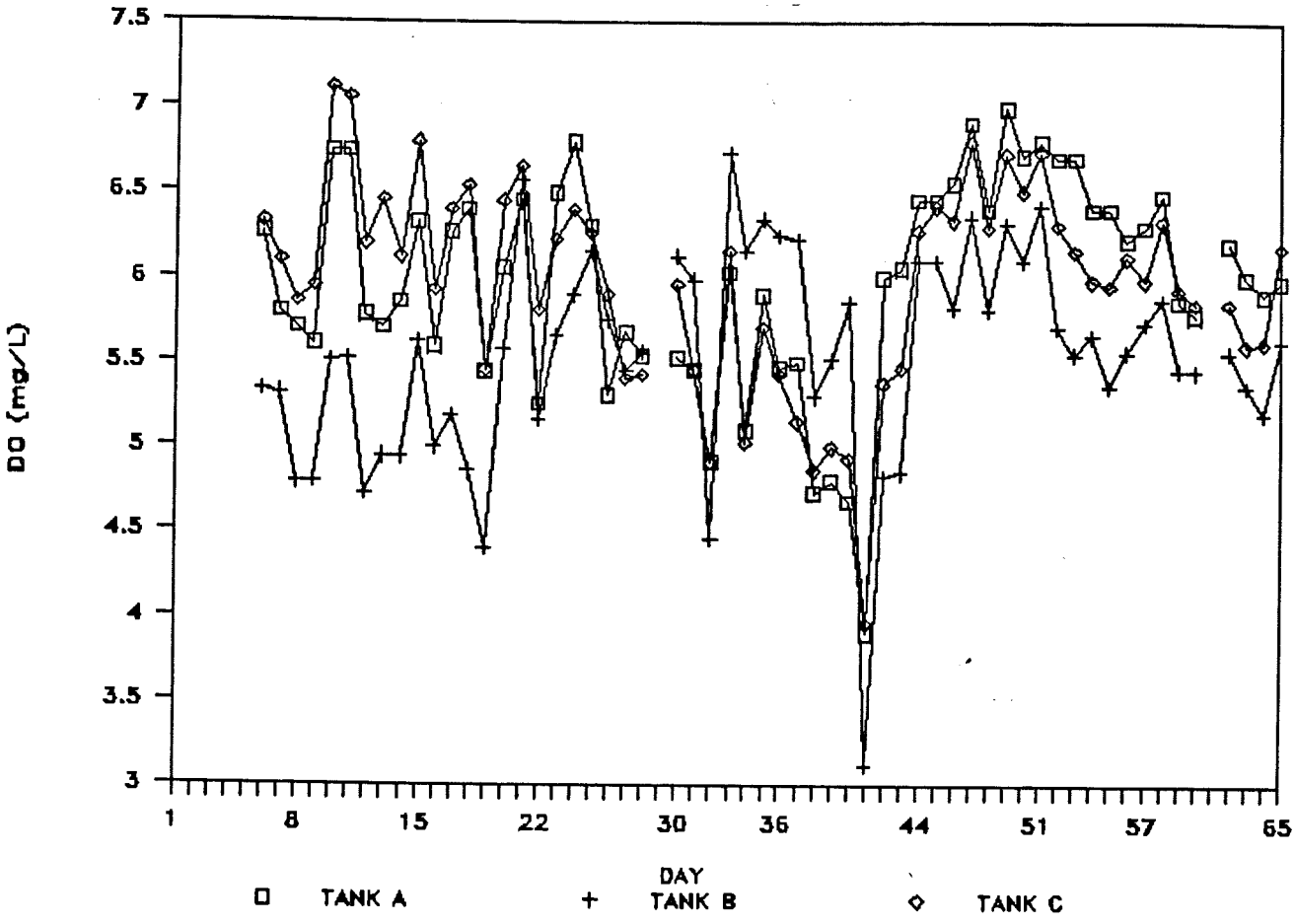

Figure 9. Saturation (%) of Oxygen for replicates A, B, and C at 28 °C.

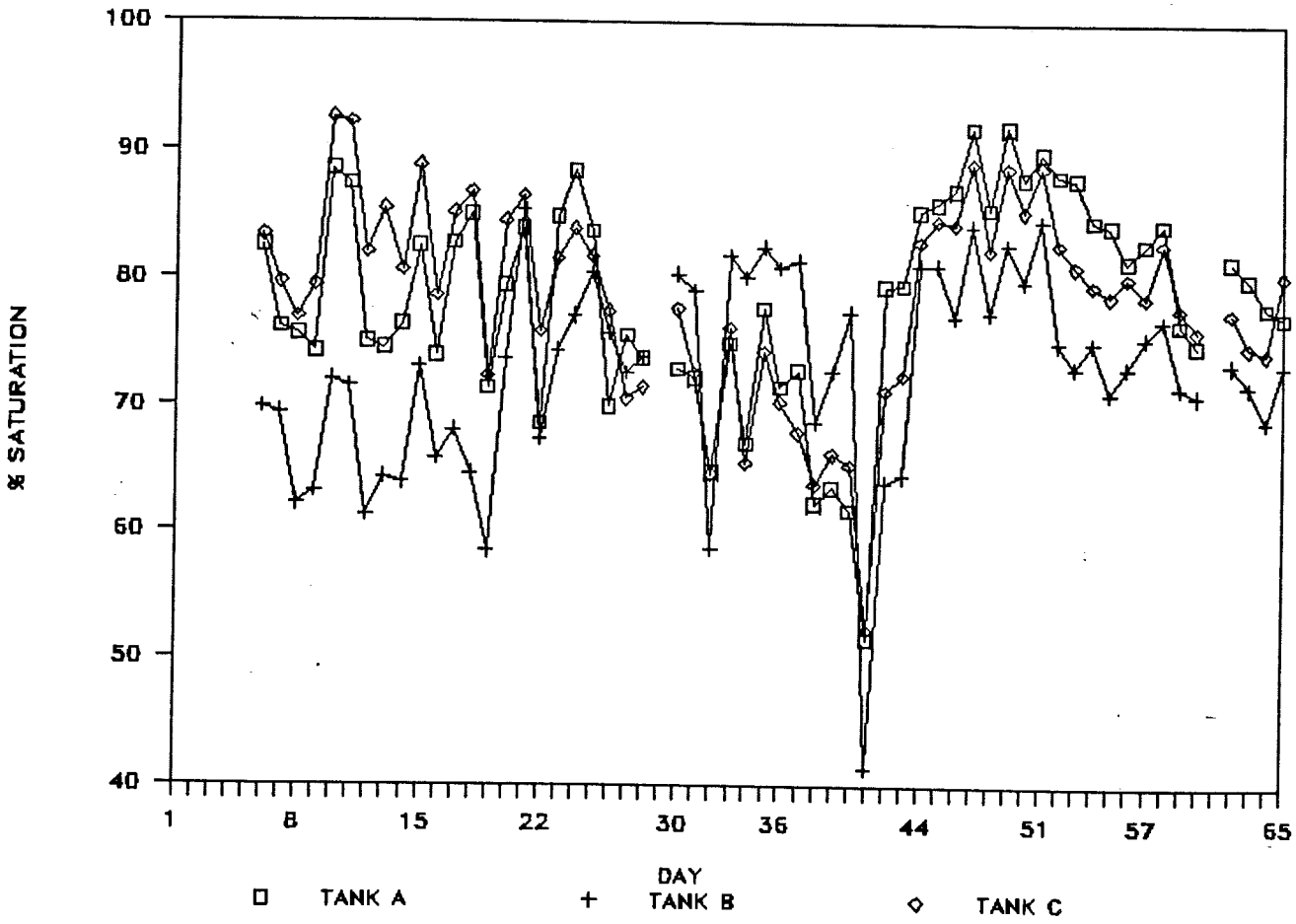

Figure 10. Dissolved Oxygen (DO) for replicates A, B, and C at 34 °C.

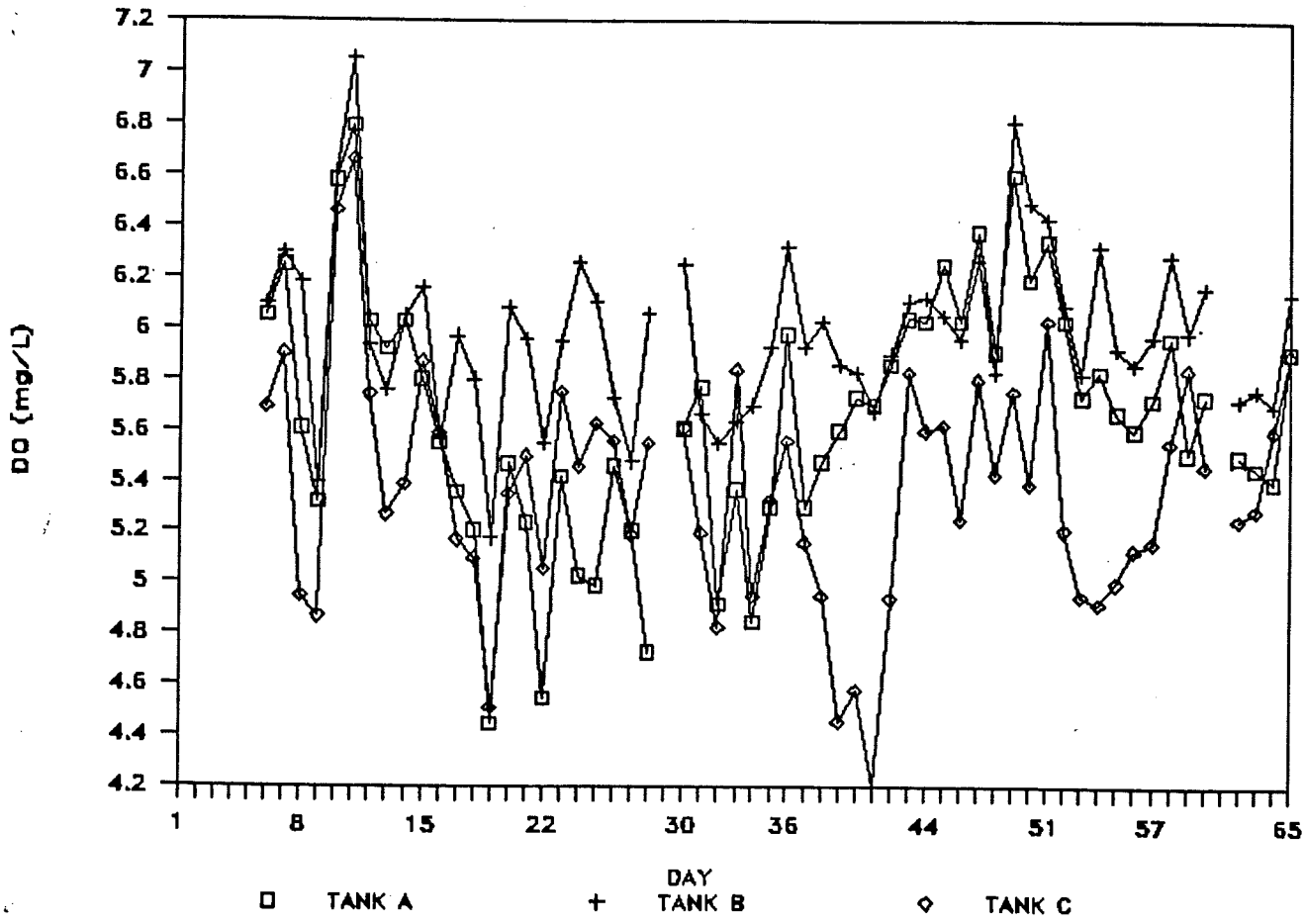

Figure 11. Saturation (%) of Oxygen for replicates A, B, and C at 34 °C.

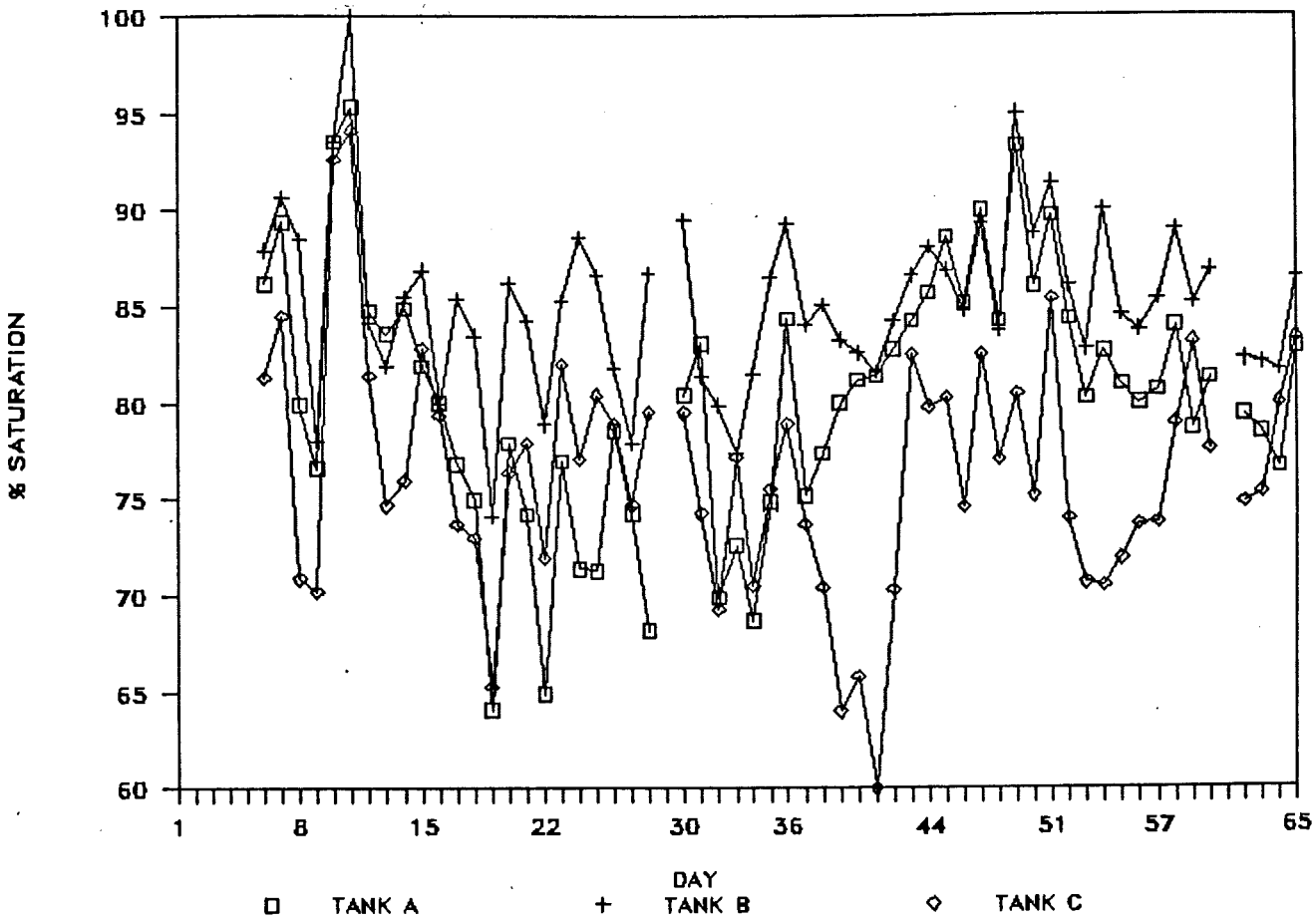

Figure 12. Total Ammonia-Nitrogen (TAN) for replicates A, B, and C at 16 °C.

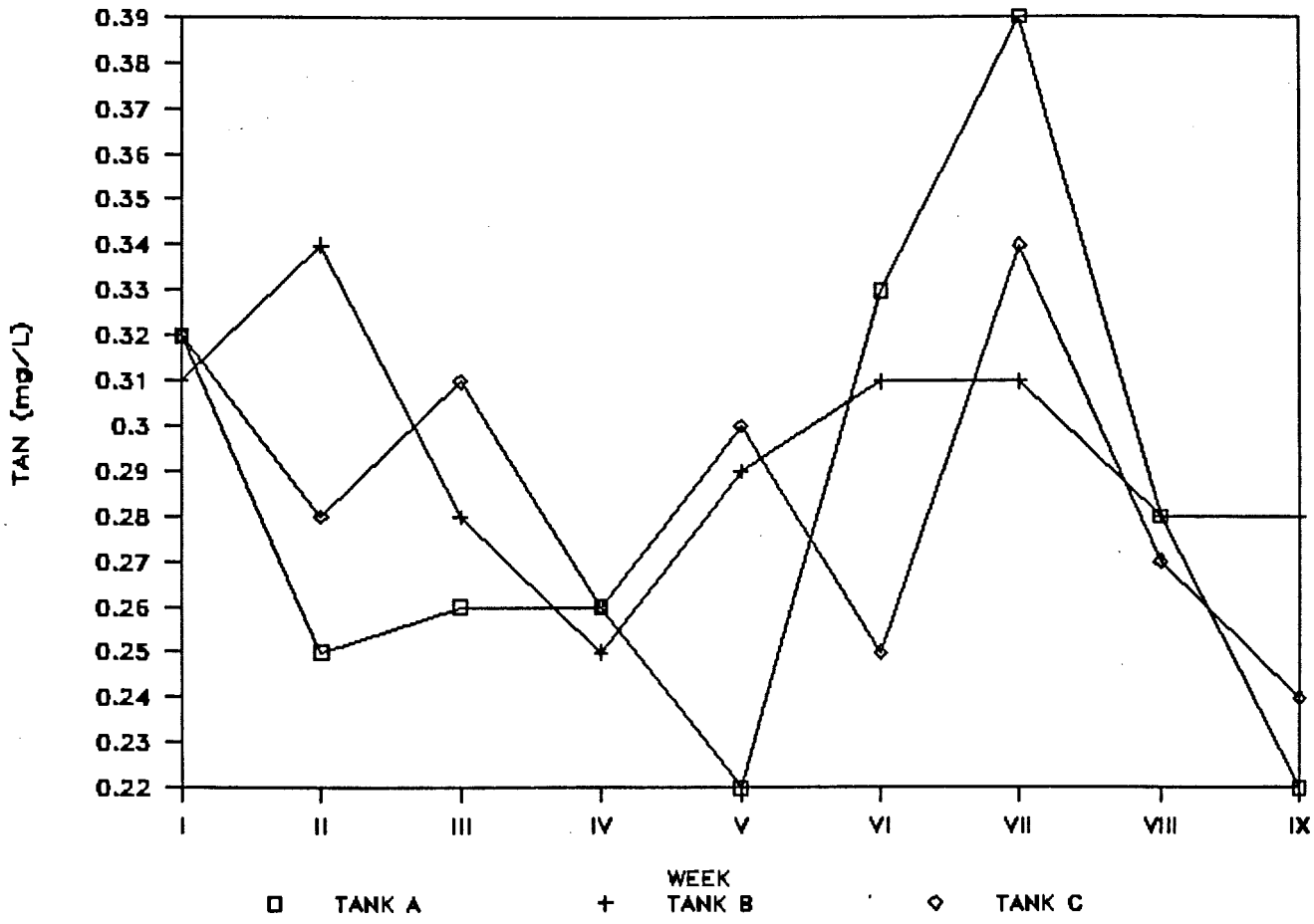

Figure 13. Total Ammonia-Nitrogen (TAN) for replicates A, B, and C at 22 °C.

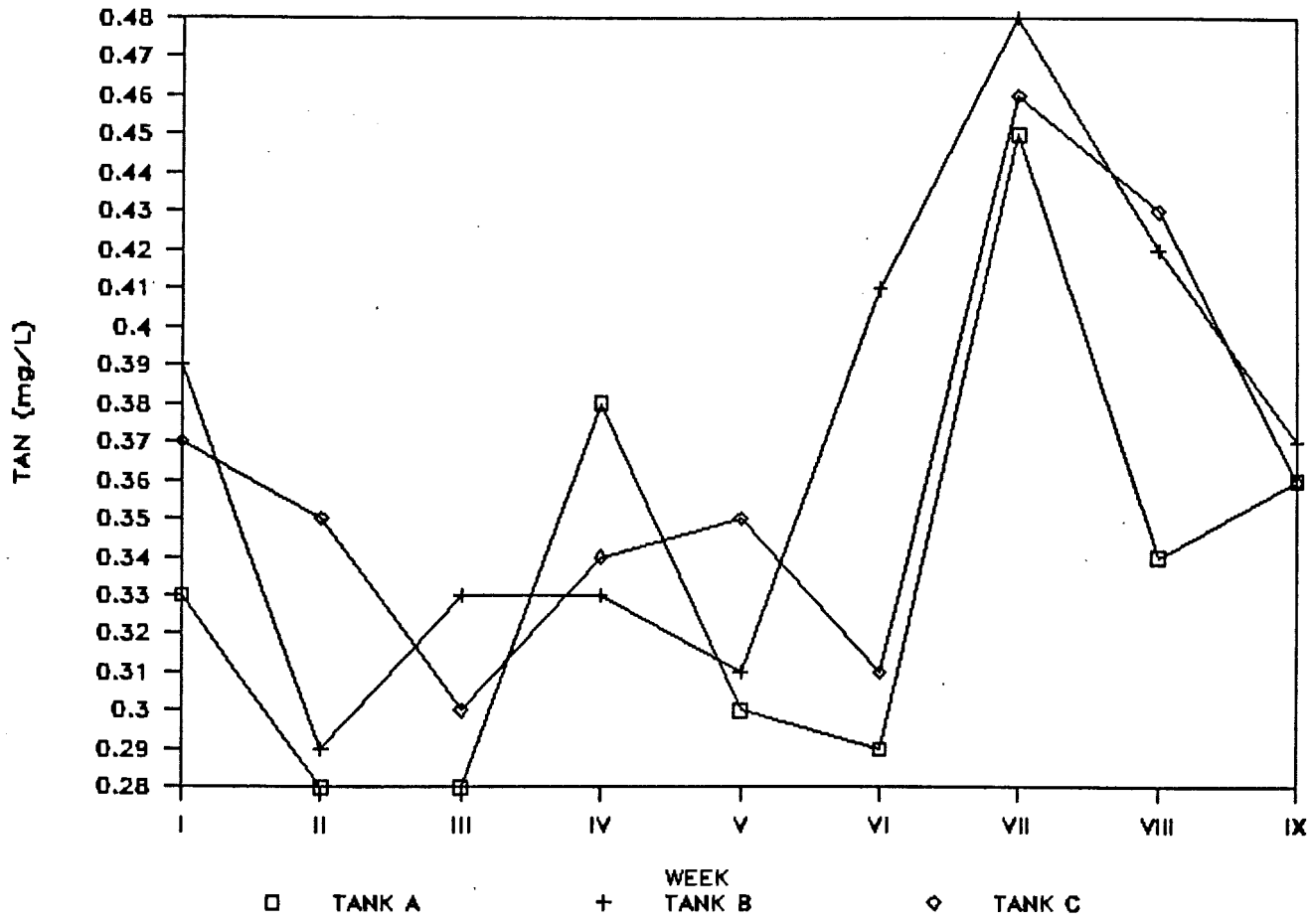

Figure 14. Total Ammonia-Nitrogen (TAN) for replicates A, B, and C at 28 °C.

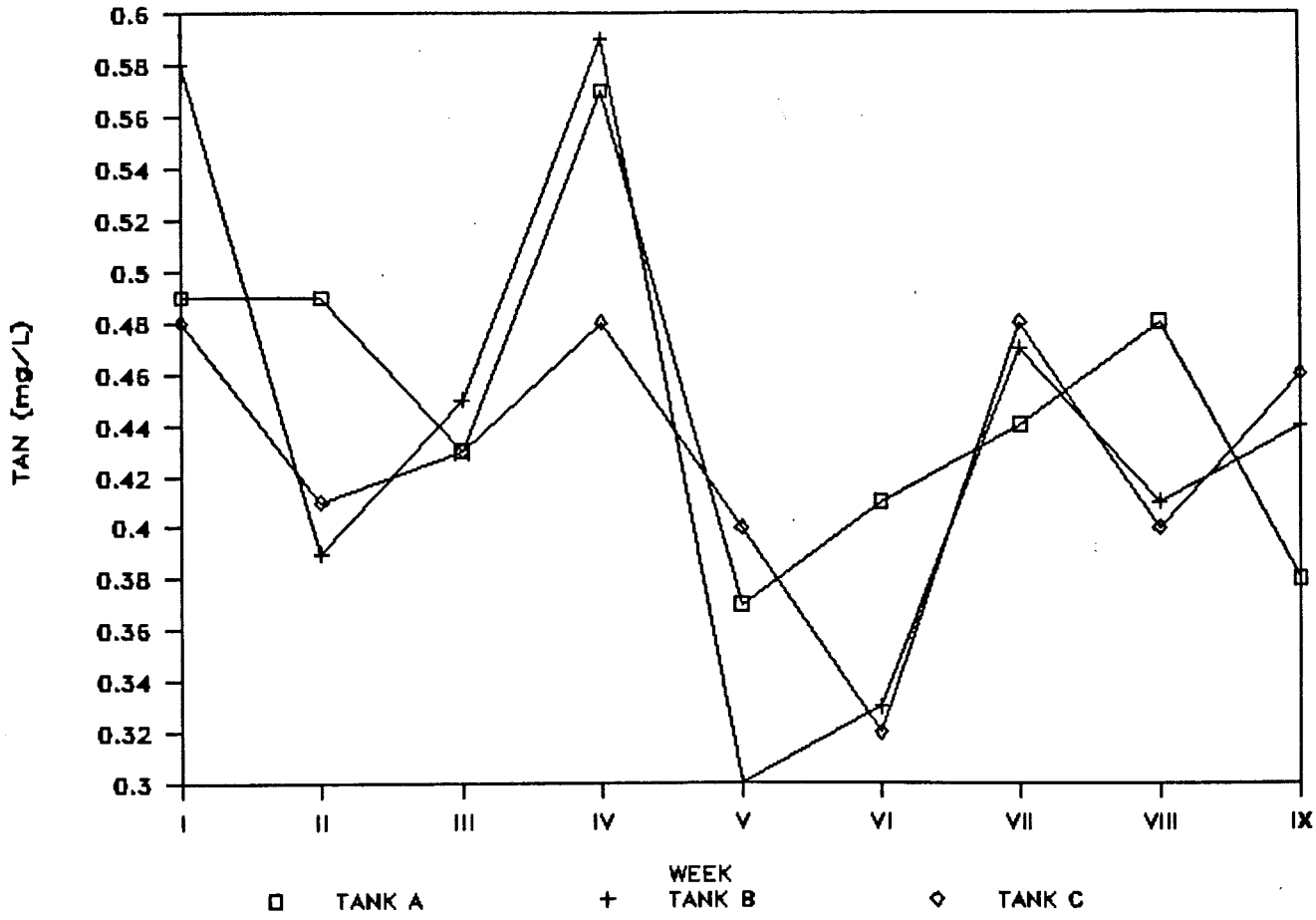

Figure 15. Total Ammonia-Nitrogen (TAN) for replicates A, B, and C at 34 °C.

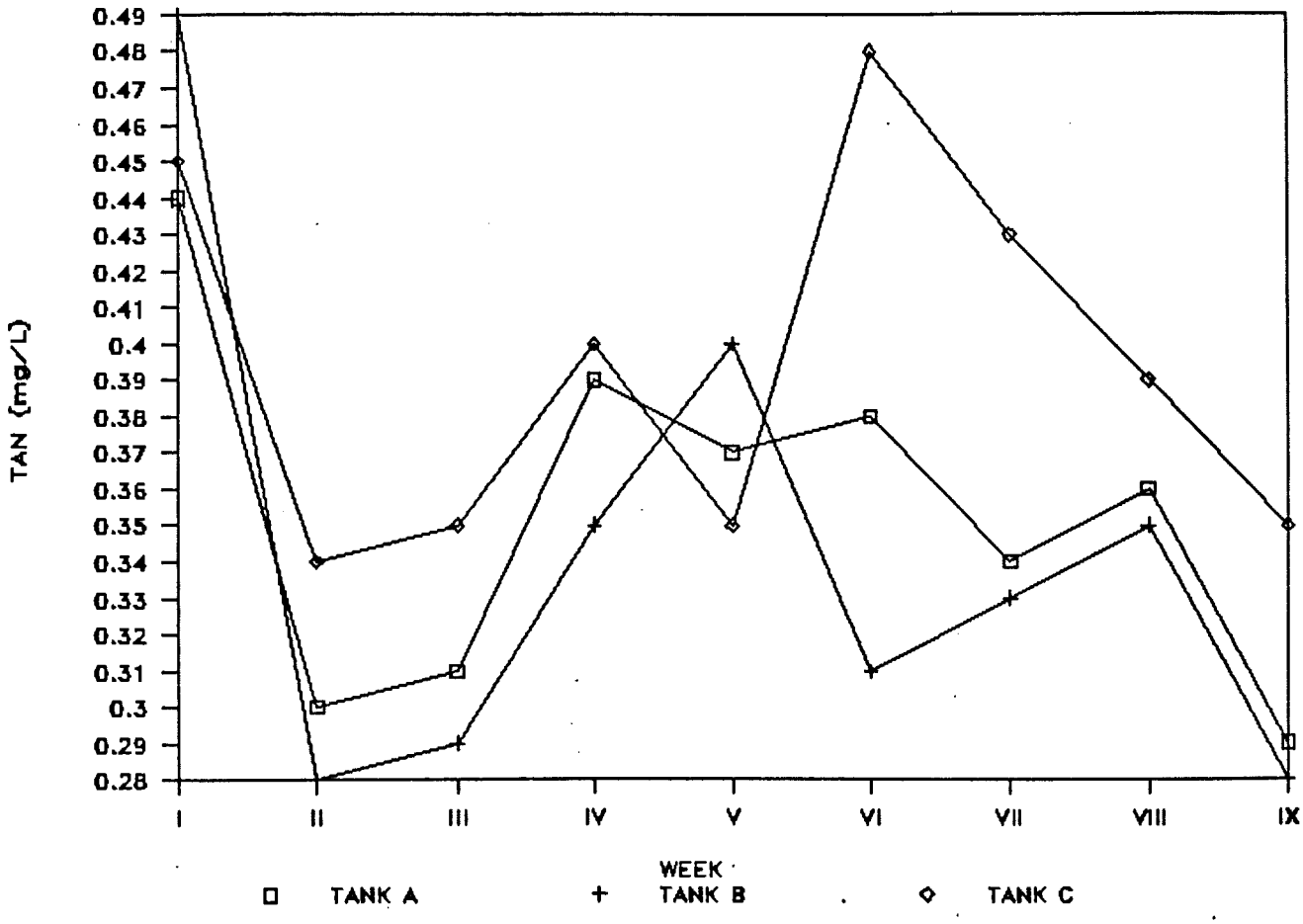

Figure 16. Nitrite-Nitrogen for replicates A, B, and C at 16 °C.

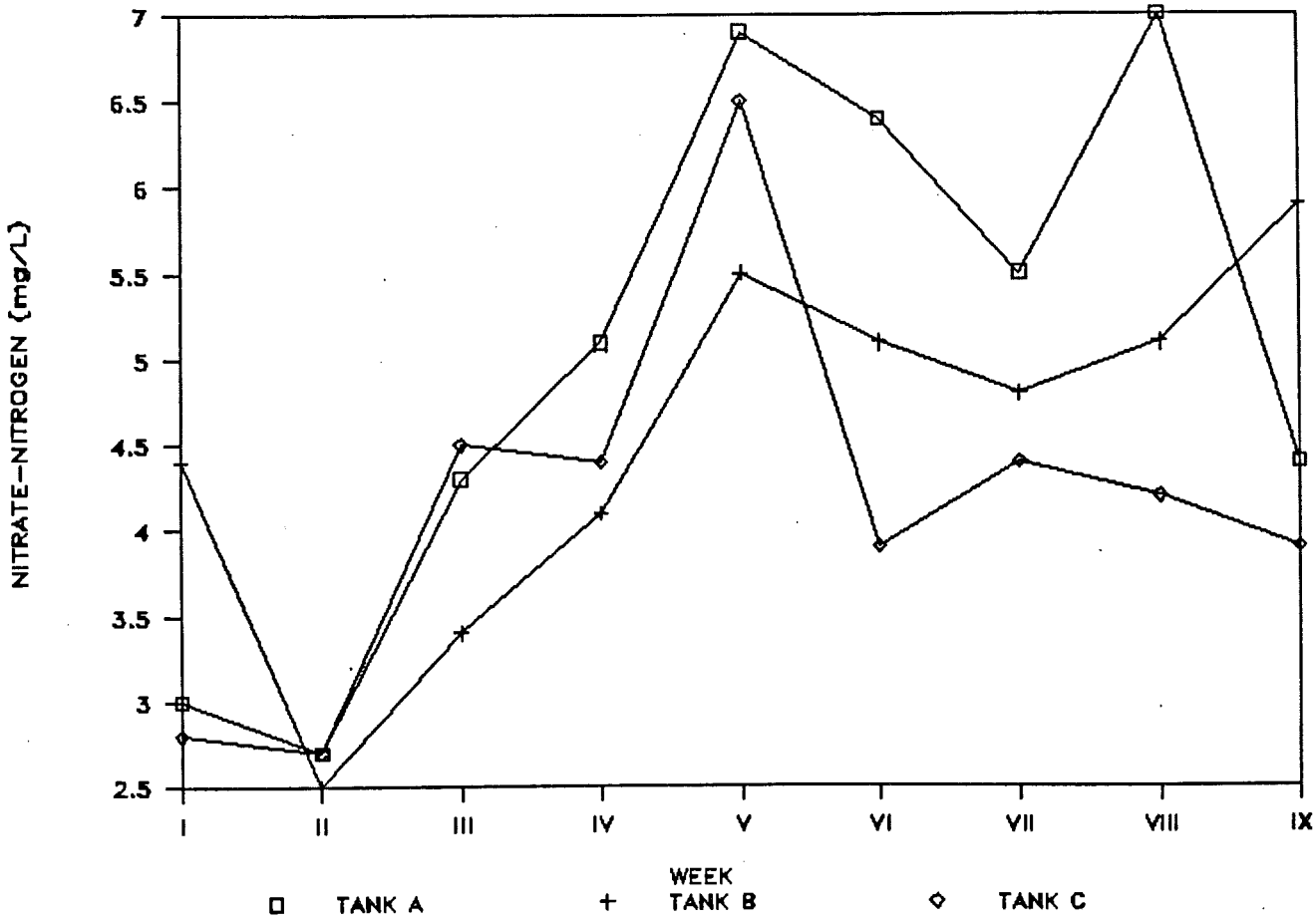

Figure 17. Nitrite-Nitrogen for replicates A, B, and C at 22 °C.

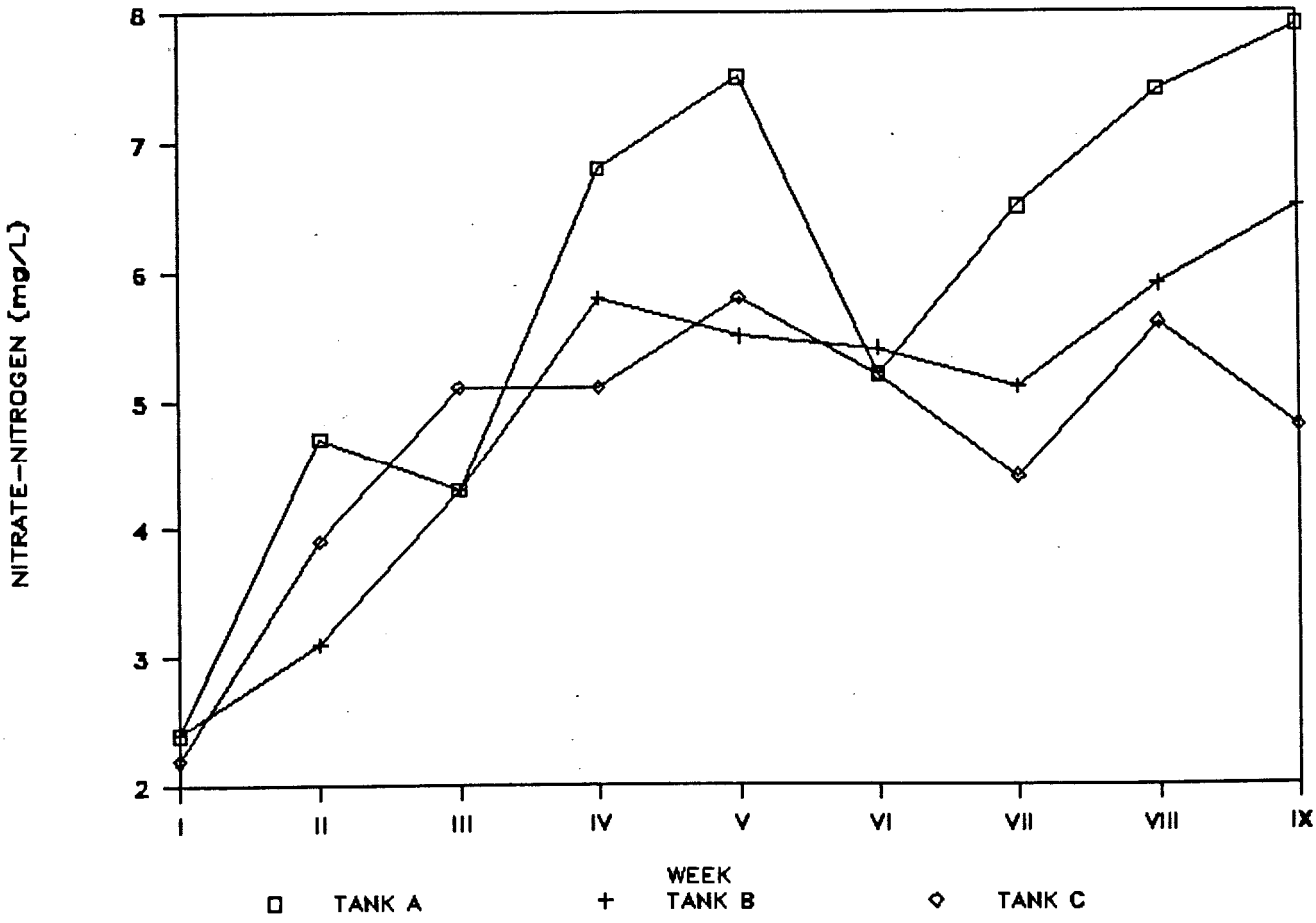

Figure 18. Nitrite-Nitrogen for replicates A, B, and C at 28 °C.

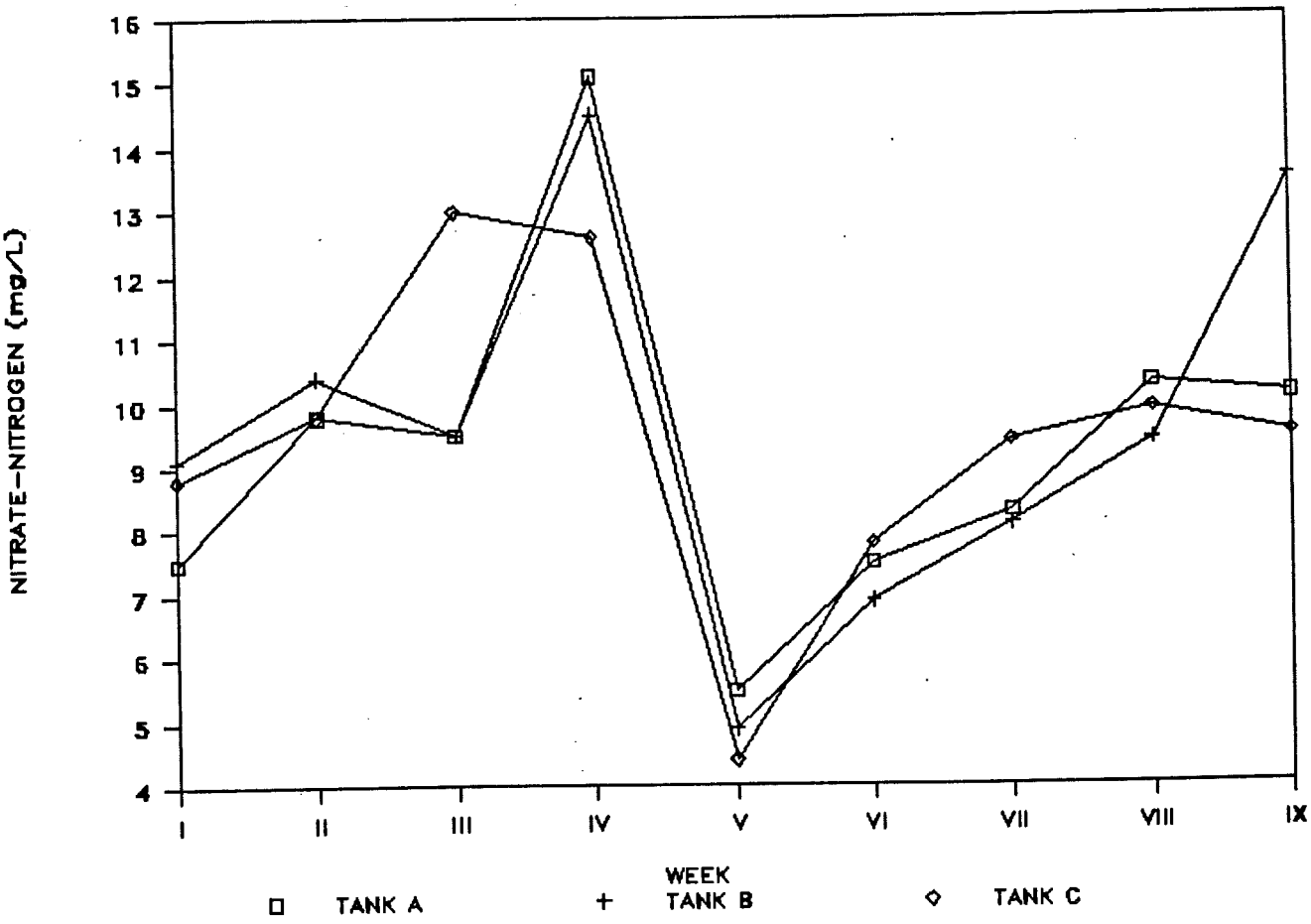

Figure 19. Nitrite-Nitrogen for replicates A, B, and C at 34 °C.

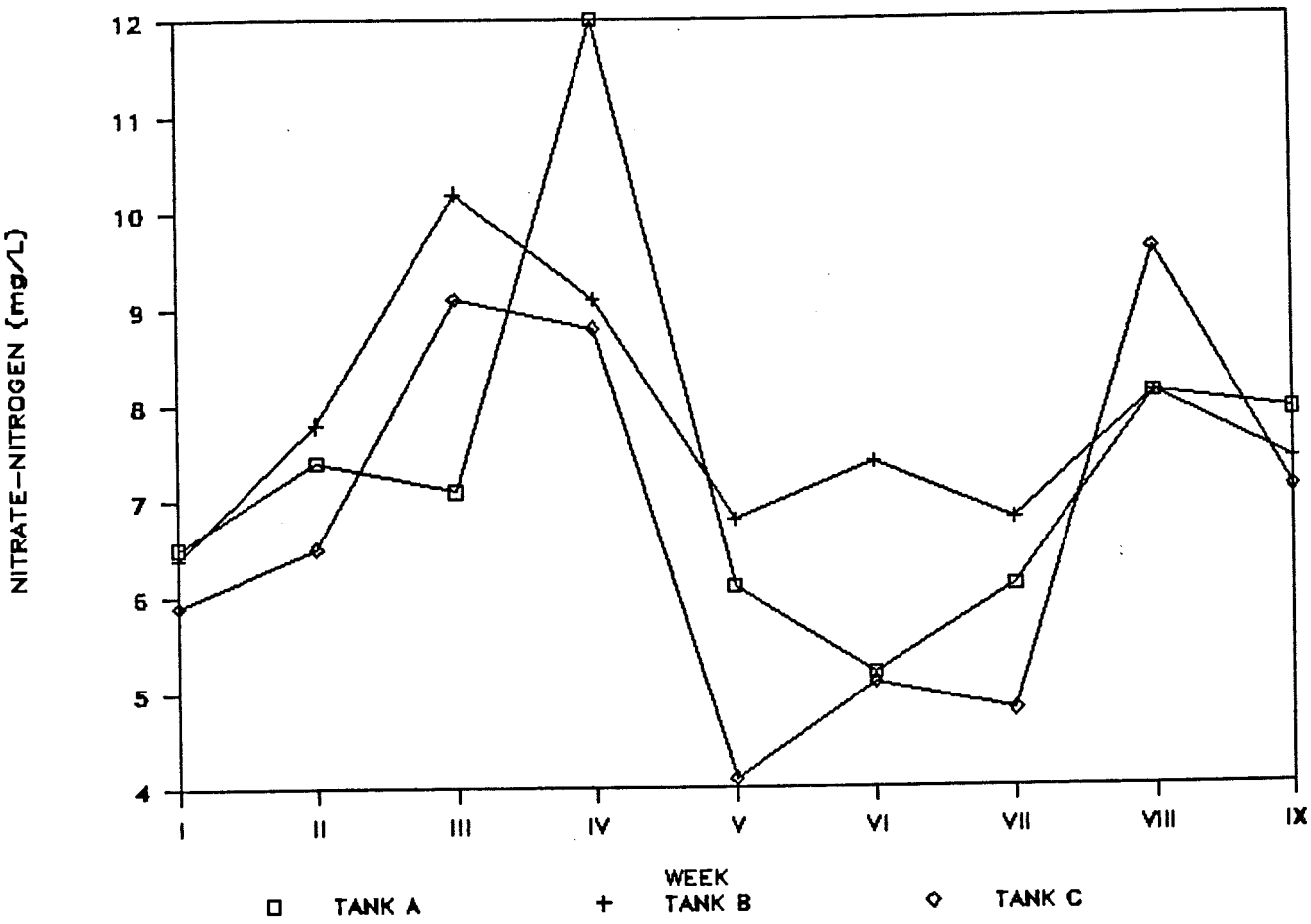

Figure 20. Nitrate-Nitrogen for replicates A, B, and C at 16 °C.

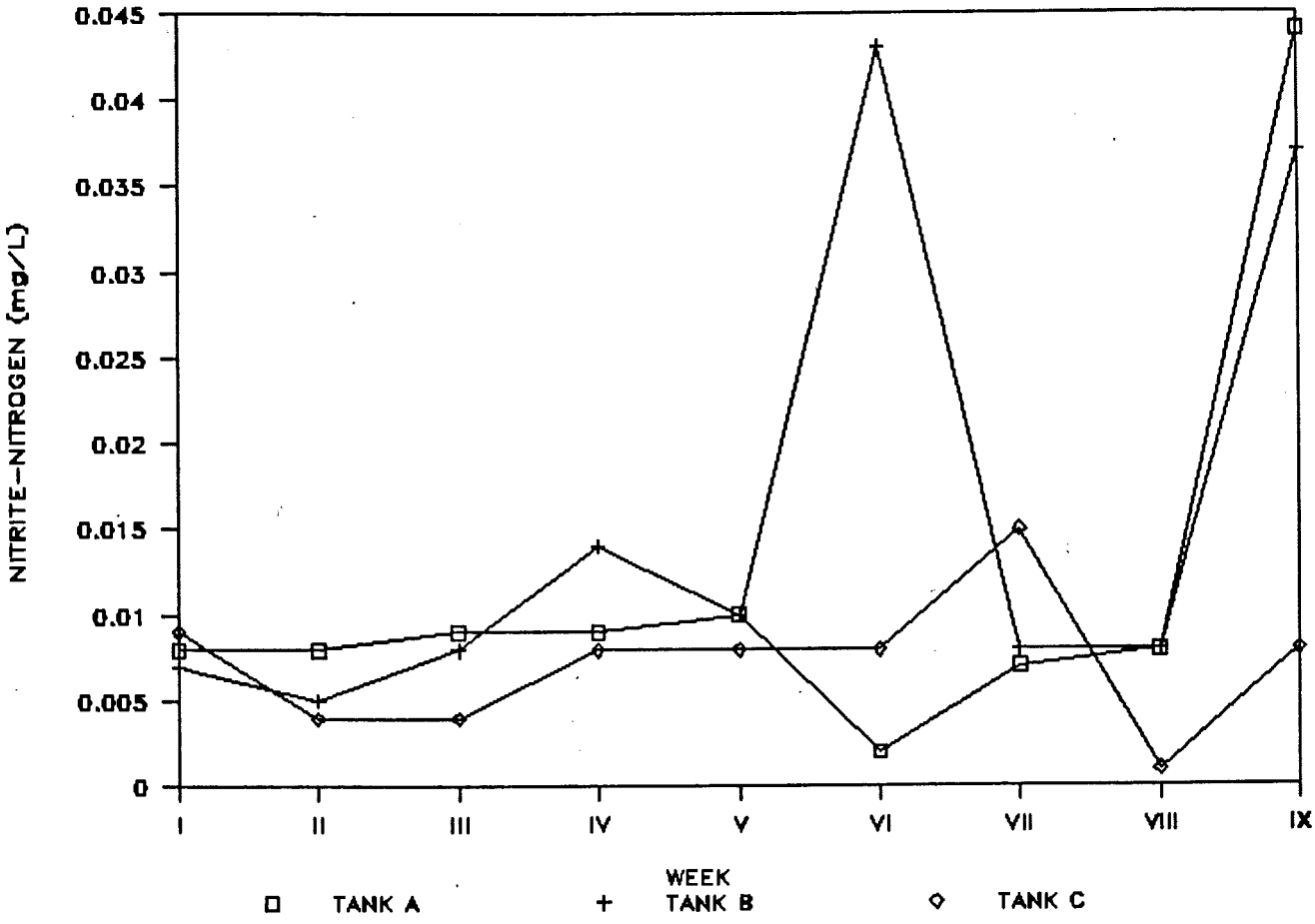

Figure 21. Nitrate-Nitrogen for replicates A, B, and C at 22 °C.

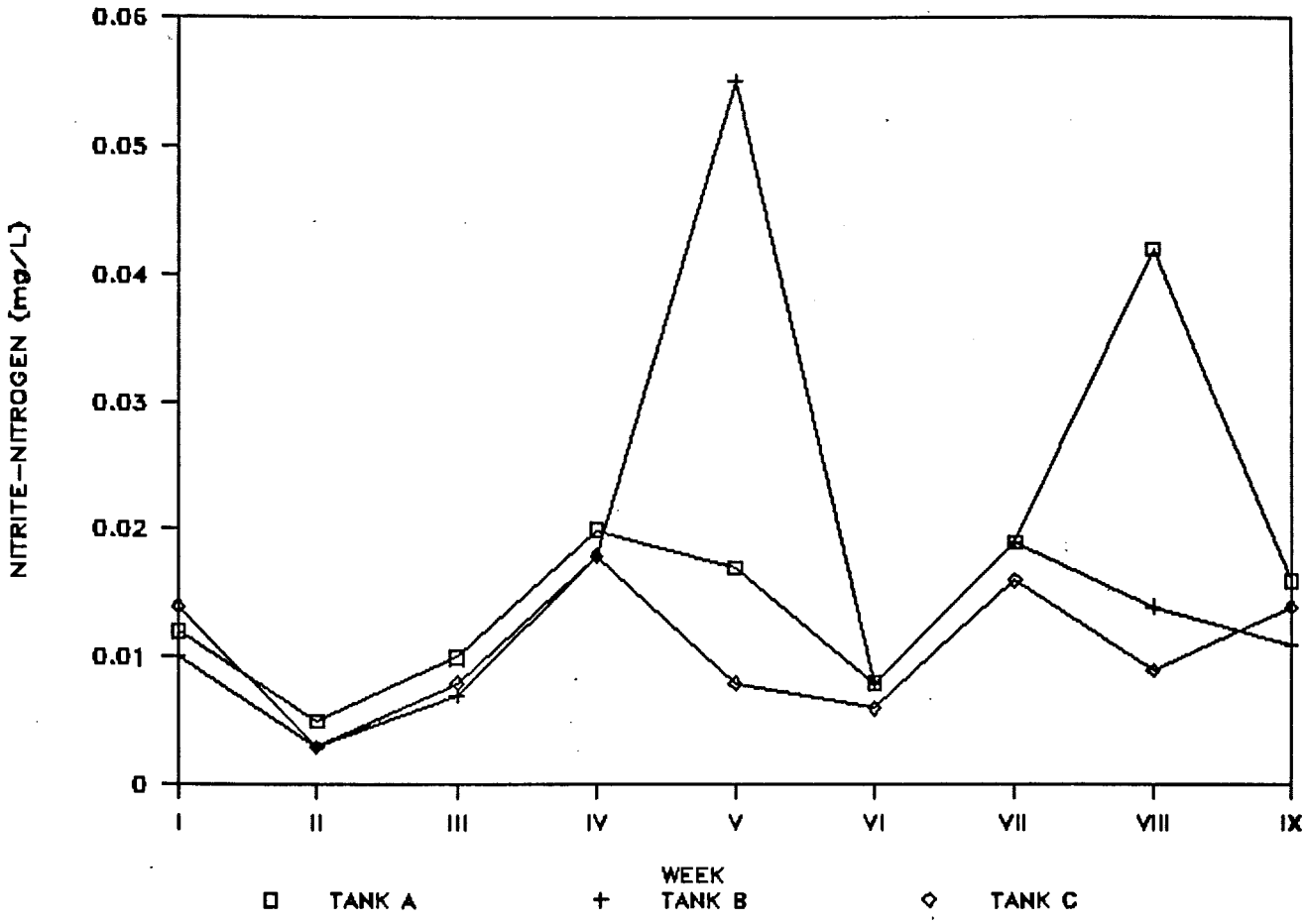

Figure 22. Nitrate-Nitrogen for replicates A, B, and C at 28 °C.

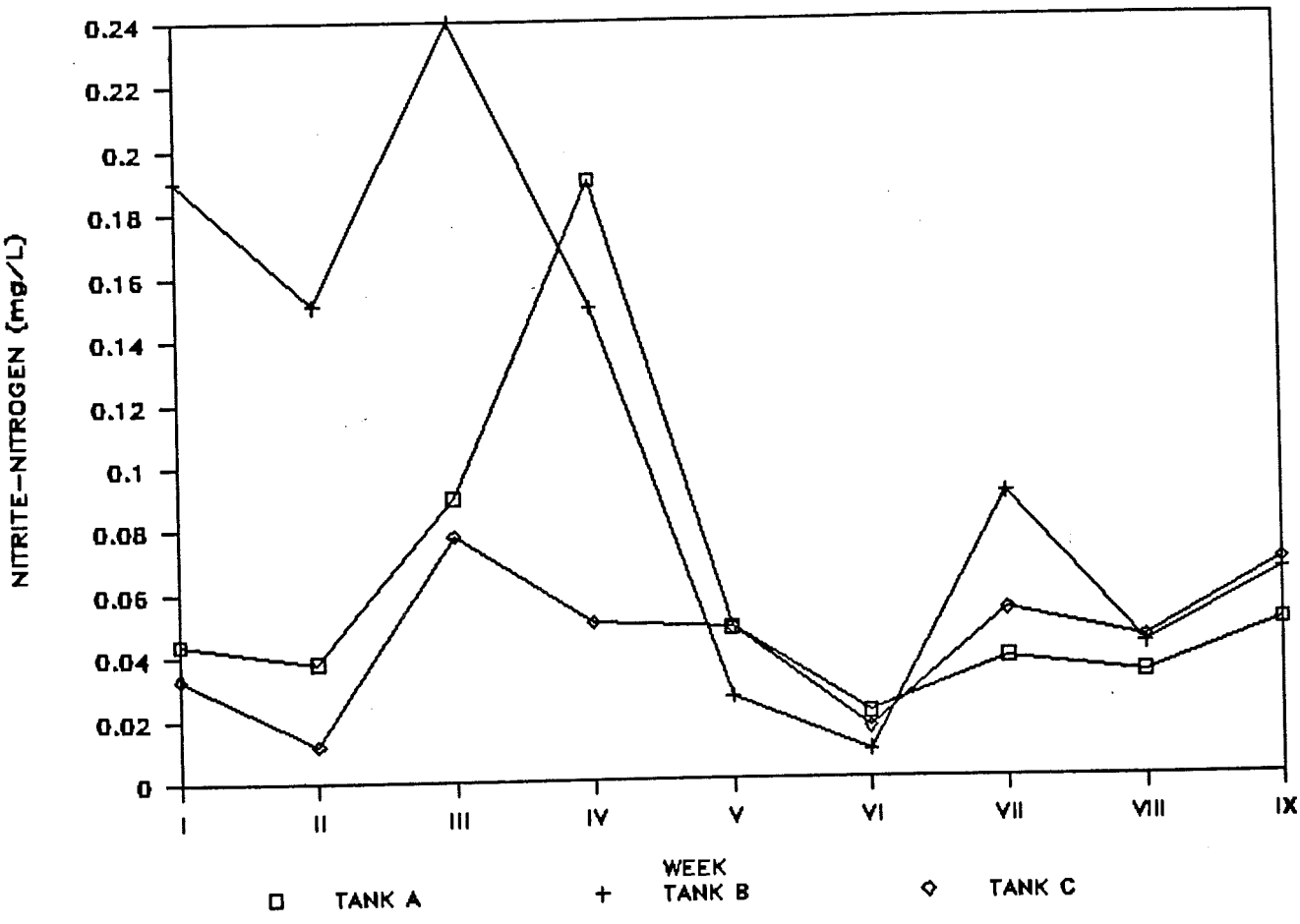

Figure 23. Nitrate-Nitrogen for replicates A, B, and C at 34 °C.

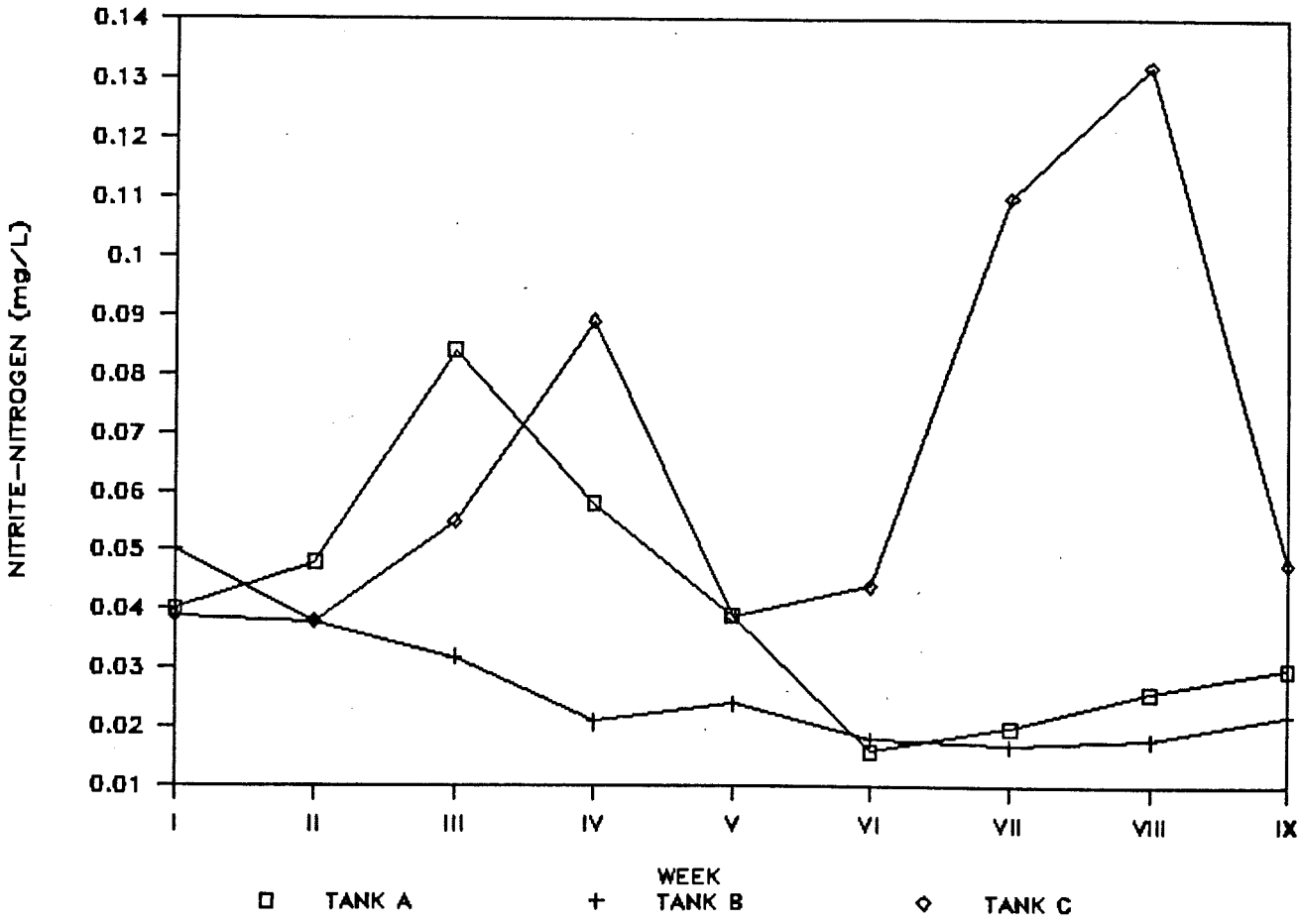

Figure 24. Alkalinity for replicates A, B, and C at 16 °C.

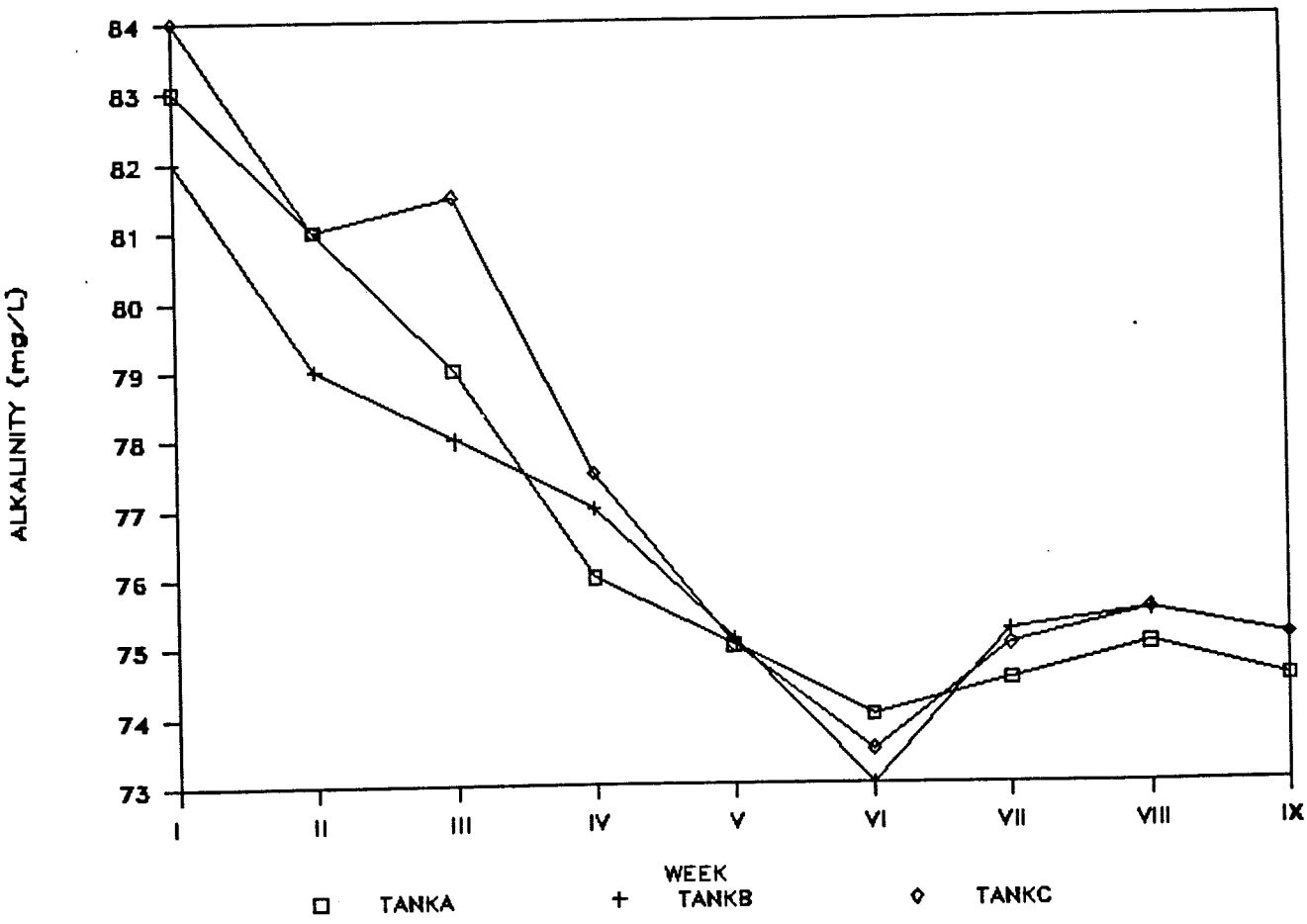

Figure 25. Alkalinity for replicates A, B, and C at 22 °C.

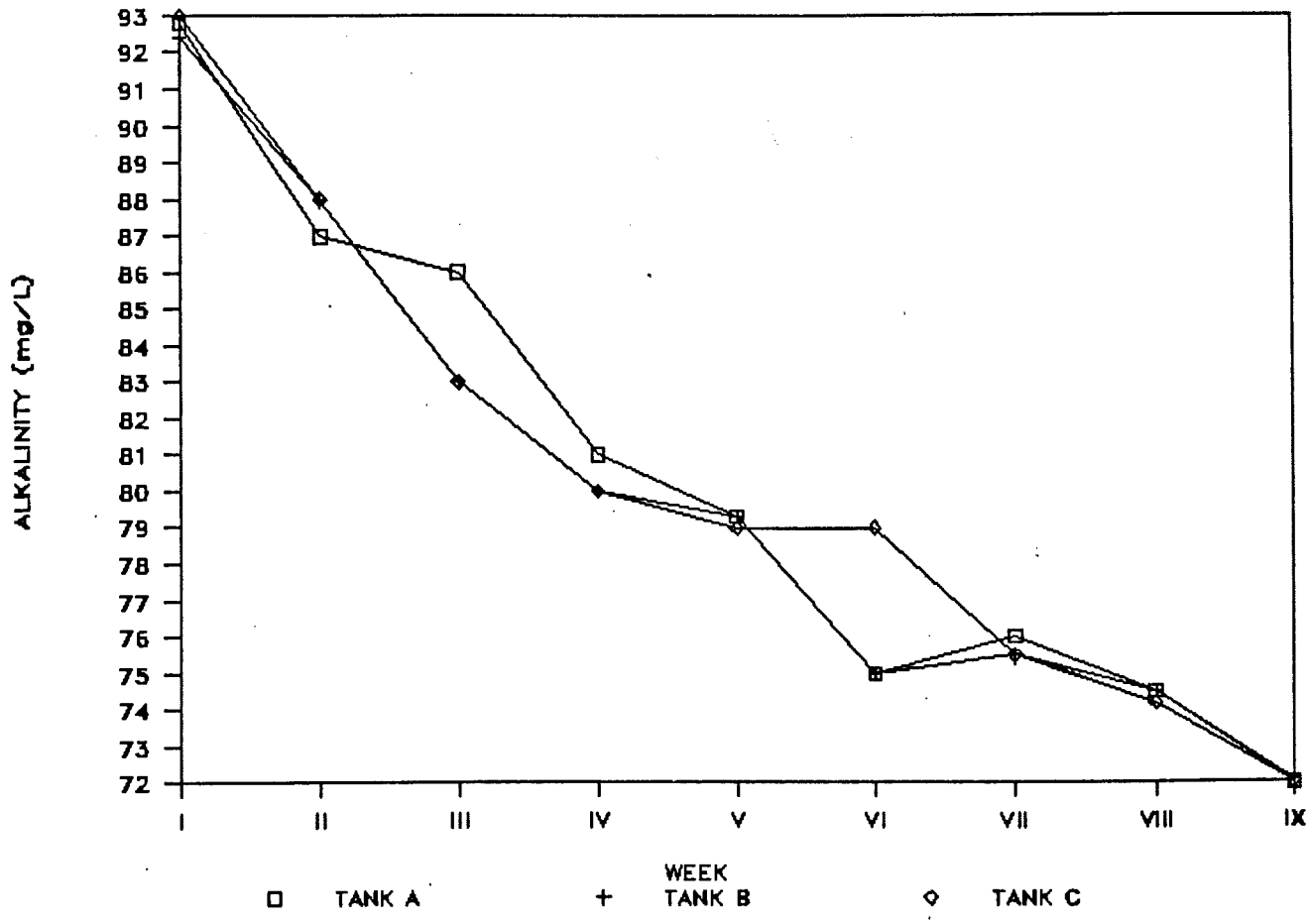

Figure 26. Alkalinity for replicates A, B, and C at 28 °C.

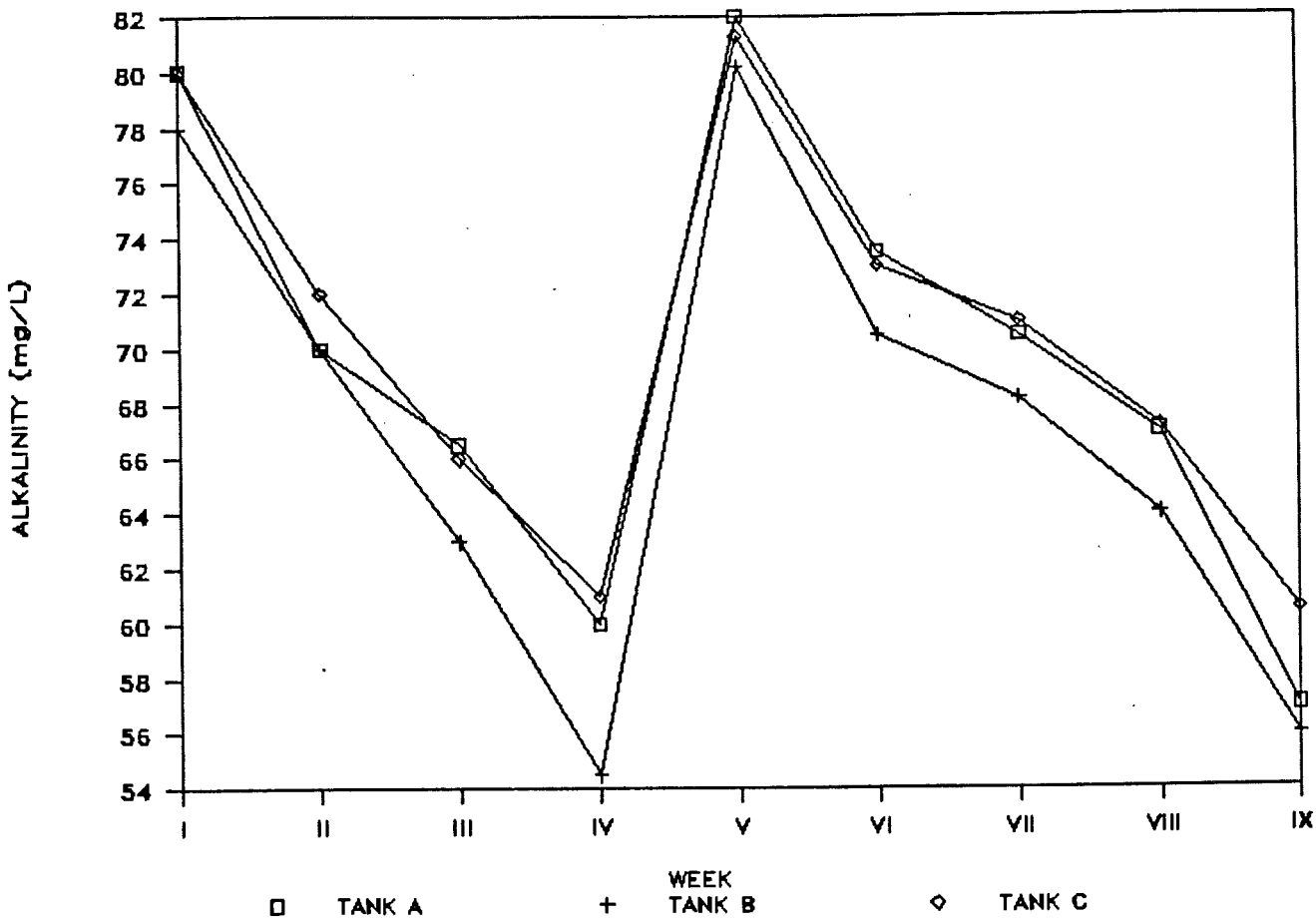

Figure 27. Alkalinity for replicates A, B, and C at 34 °C.

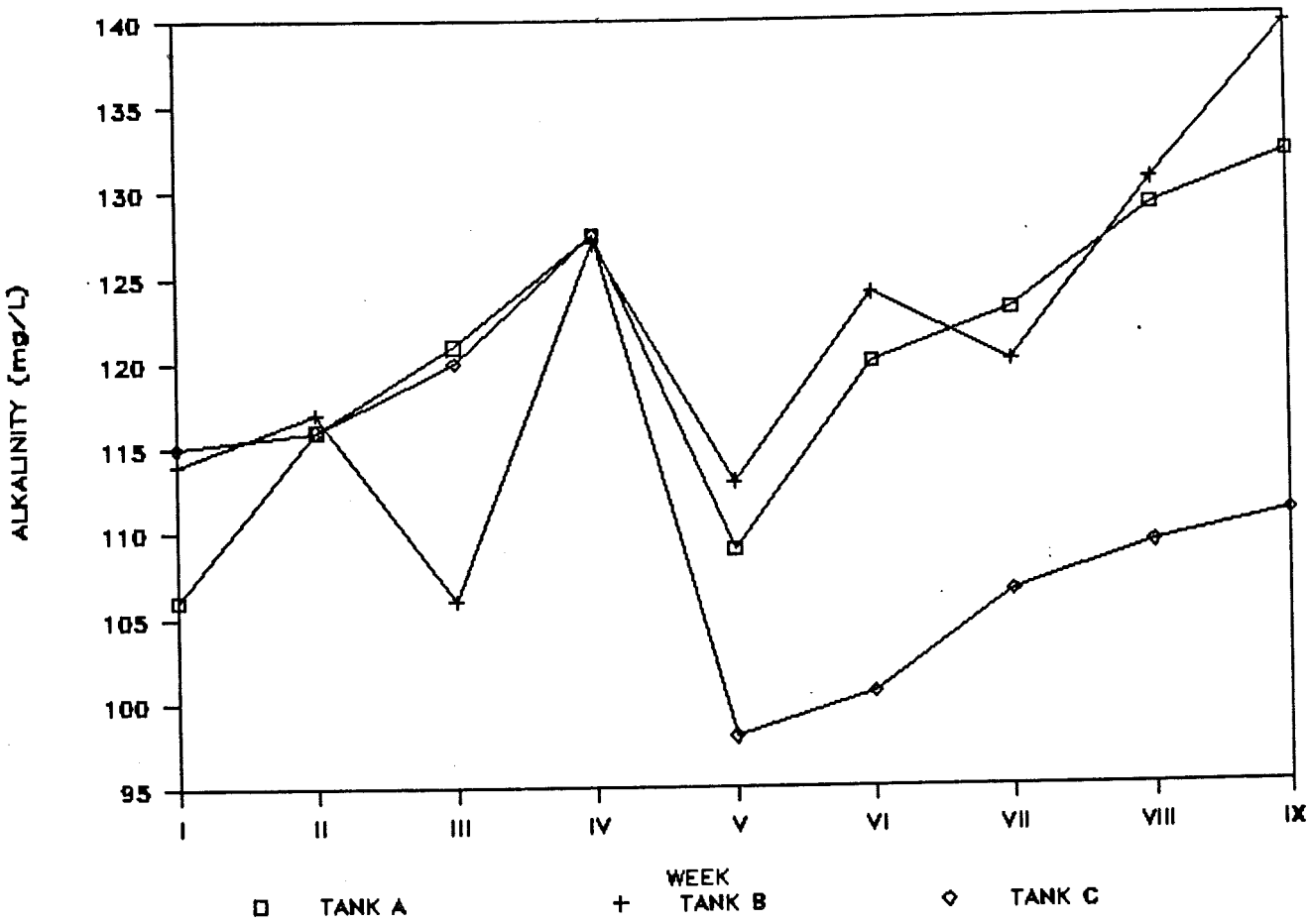

Figure 28. pH for replicates A, B, and C at 16 ^{o}C.

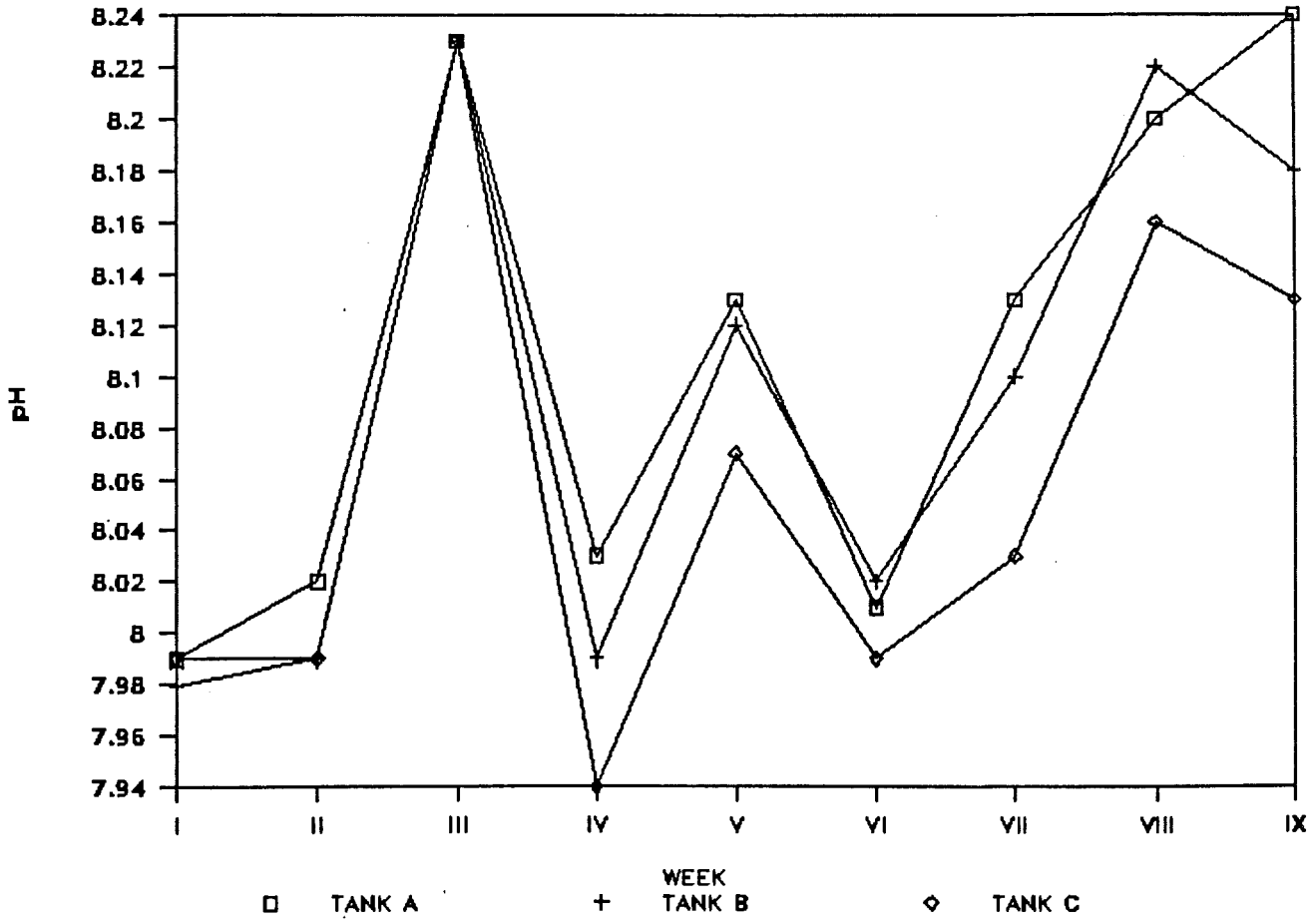

Figure 29. pH for replicates A, B, and C at 22 °C.

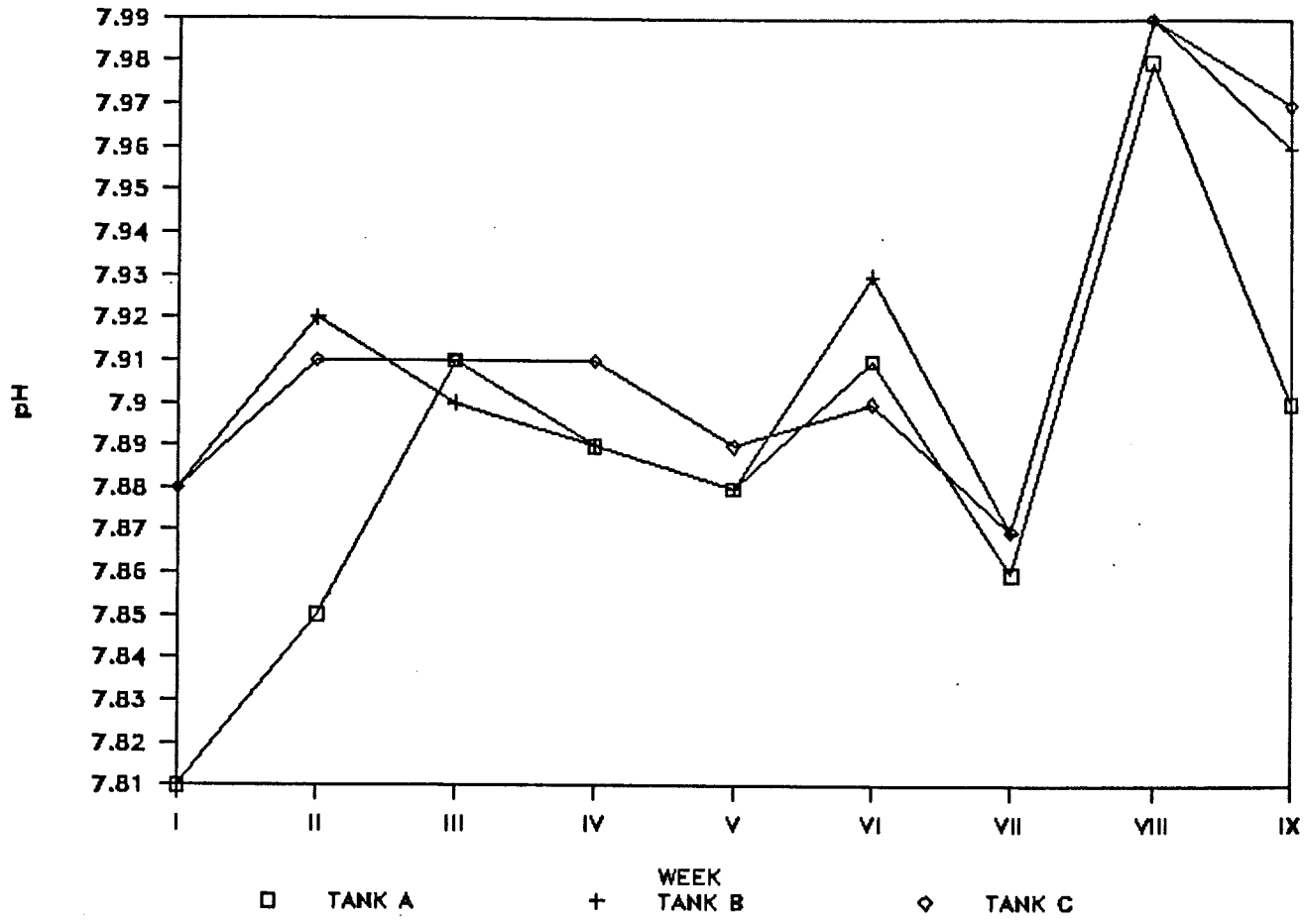

Figure 30. pH for replicates A, B, and C at 28 °C.

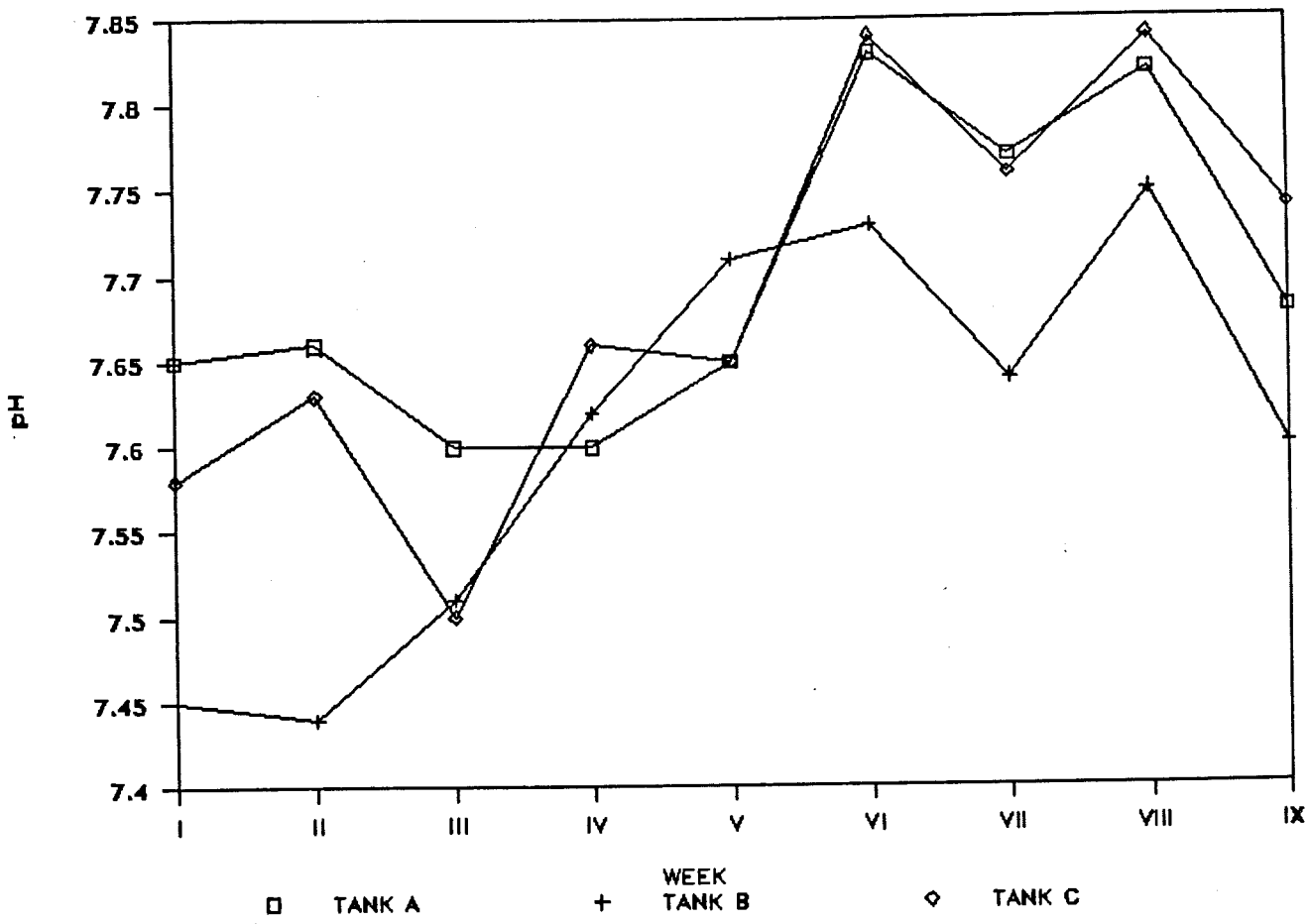

Figure 31. pH for replicates A, B, and C at 34 ^{o}C.

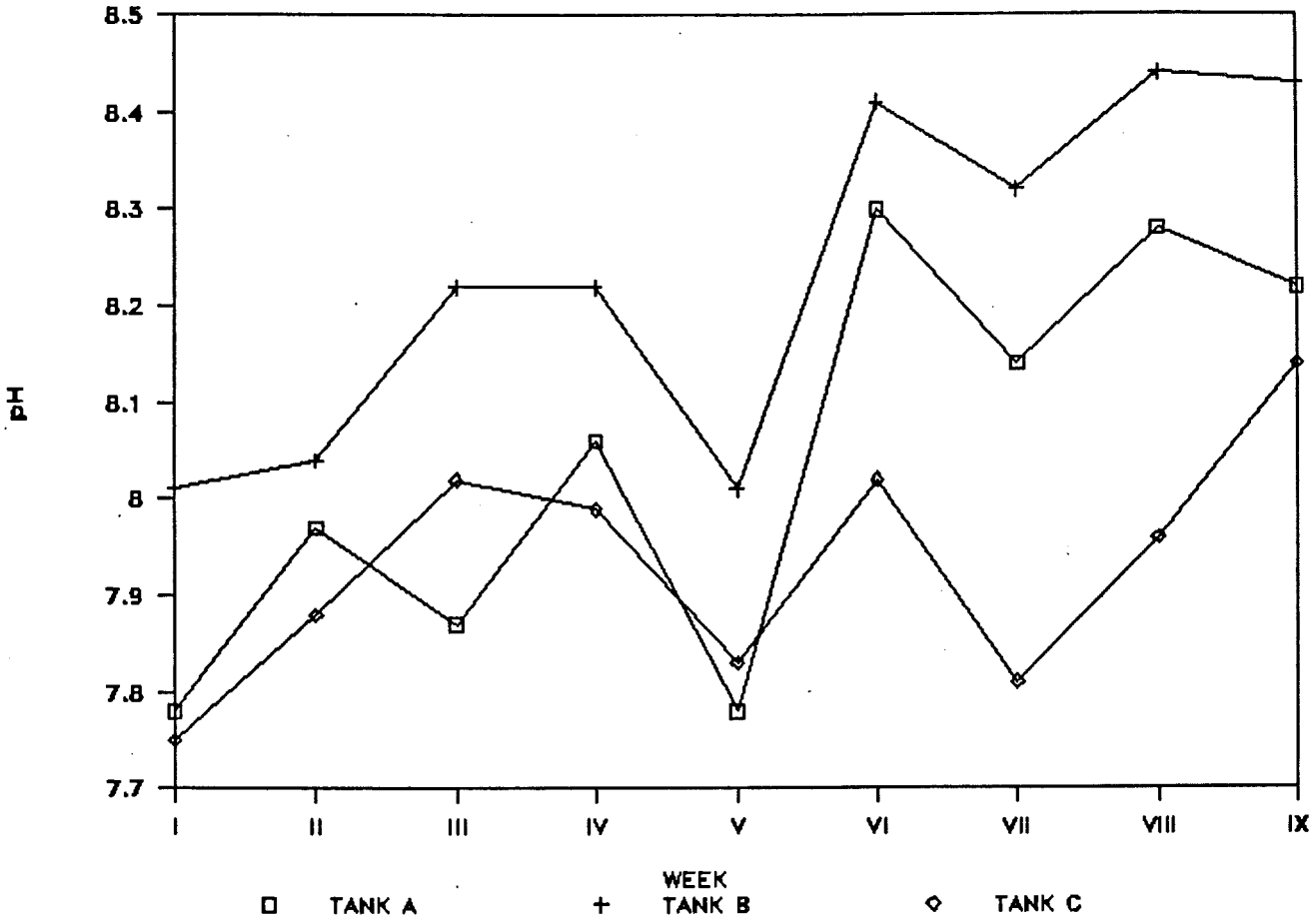

Figure 32. Average weight of black bullhead at week I, week II, week VI and week IX (day in bracket) maintained at 16, 22, 28 and 34 °C in Wet Laboratory II of SUNY College at Brockport.

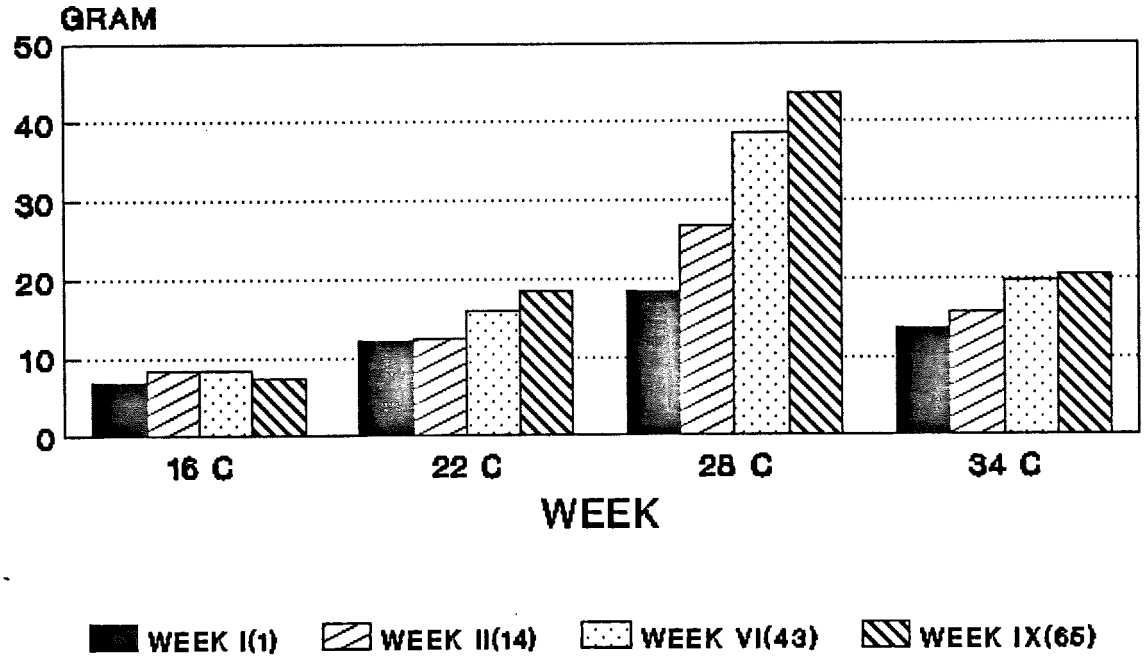

Figure 33. Weekly mortalities of black bullhead maintained at 16, 22, 28 and 34 °C in Wet Laboratory II of SUNY College at Brockport. Fish were weighed on day 1 (week 1), day 14 (week 2), day 43 (week 6) and at harvest (day 65; week 9).

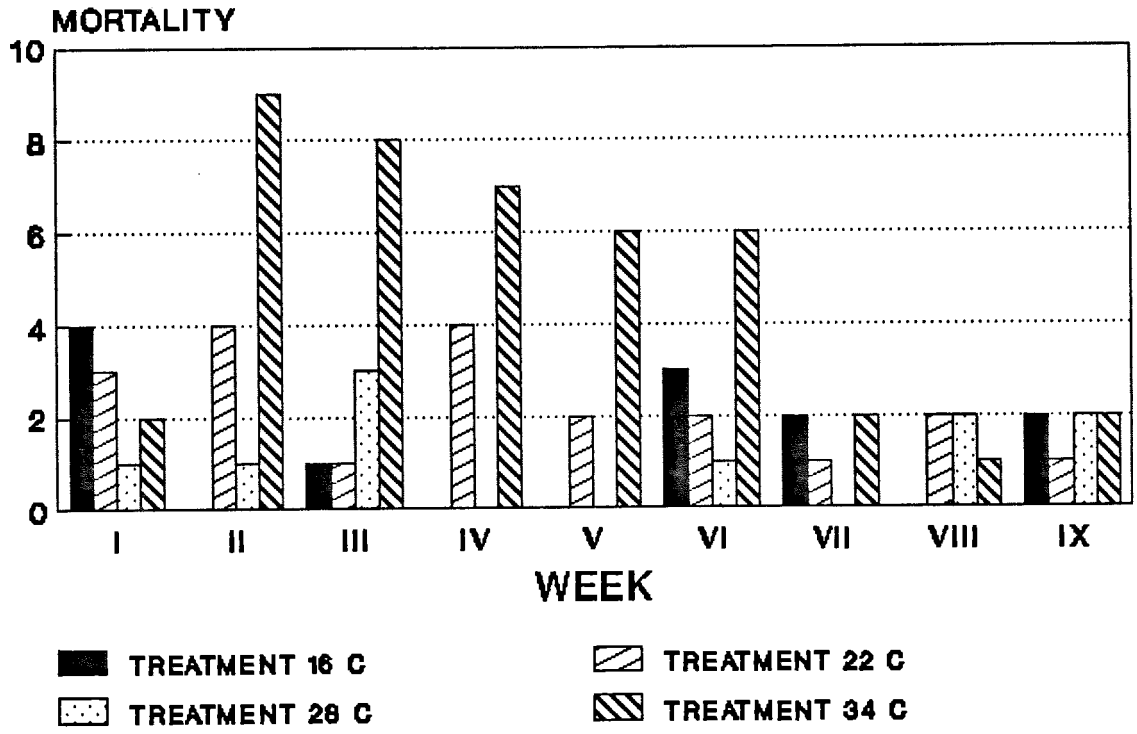

Figure 34. Survival (%) of black bullhead maintained for nine weeks at 16, 22, 28 and 34 °C.

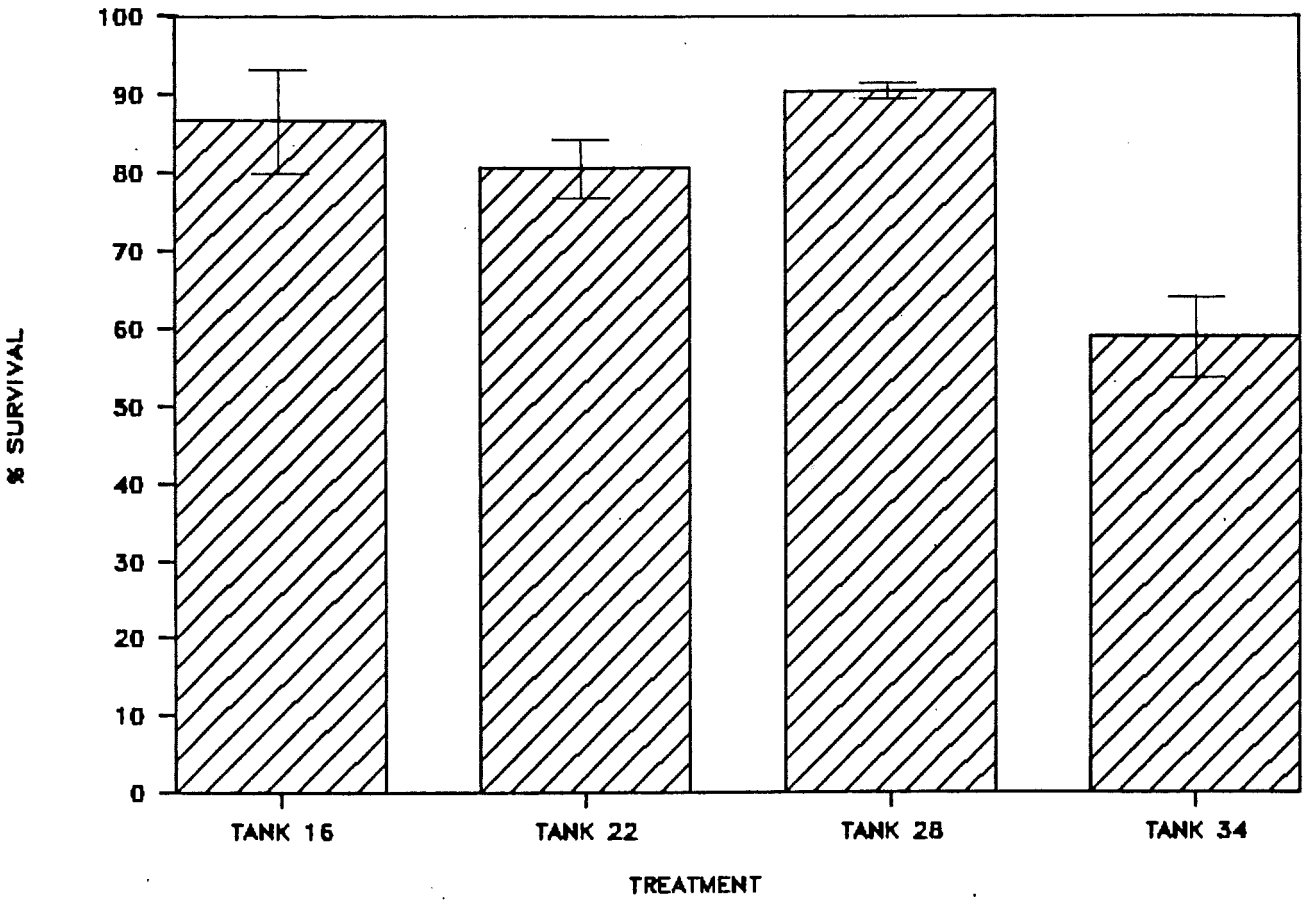

Figure 35. Growth (%) of black bullhead maintained for nine weeks at 16, 22, 28 and 34 °C.

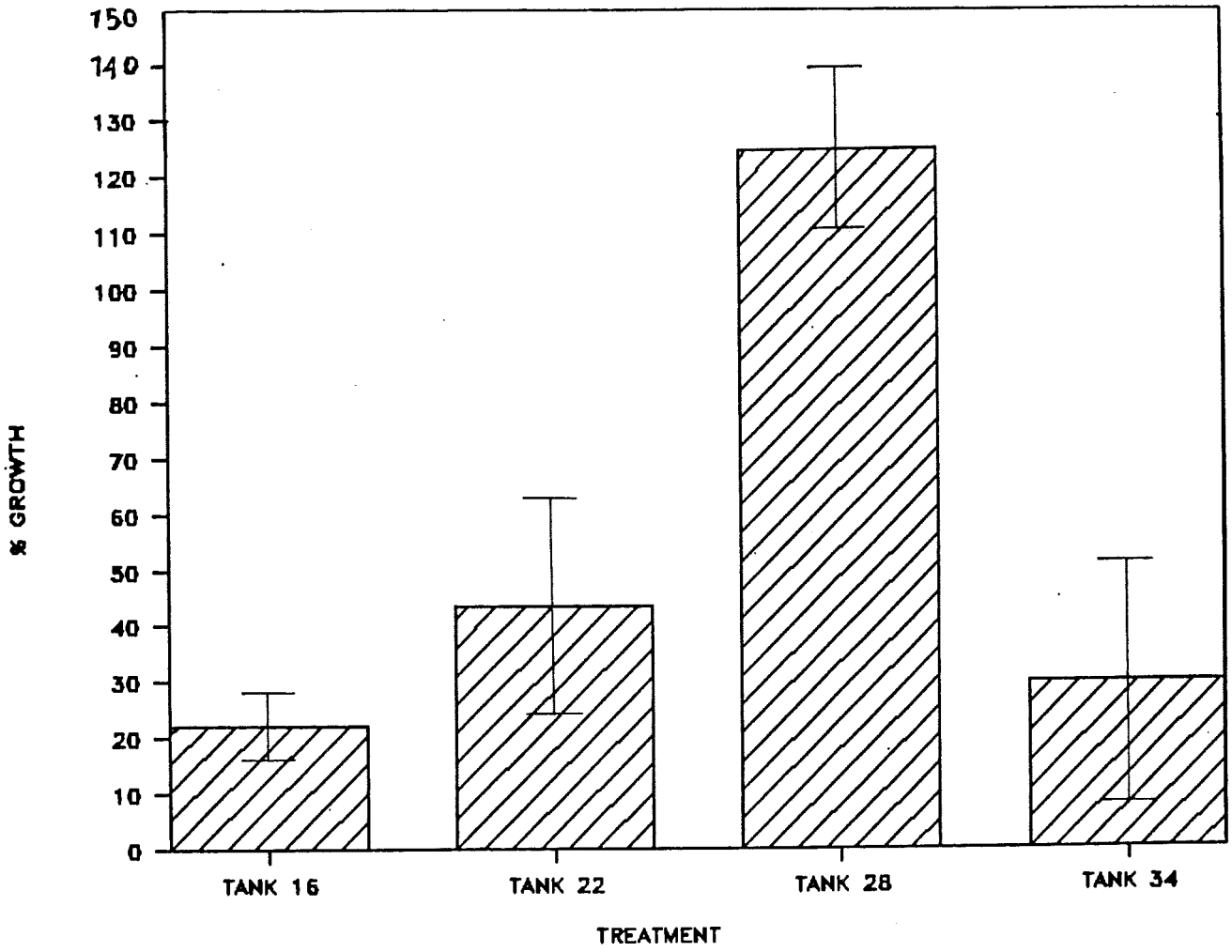

Figure 36. Amount of food ingested (g) per gram of black bullhead harvested for fish maintained nine weeks at 16, 22, 28 and 34 °C.

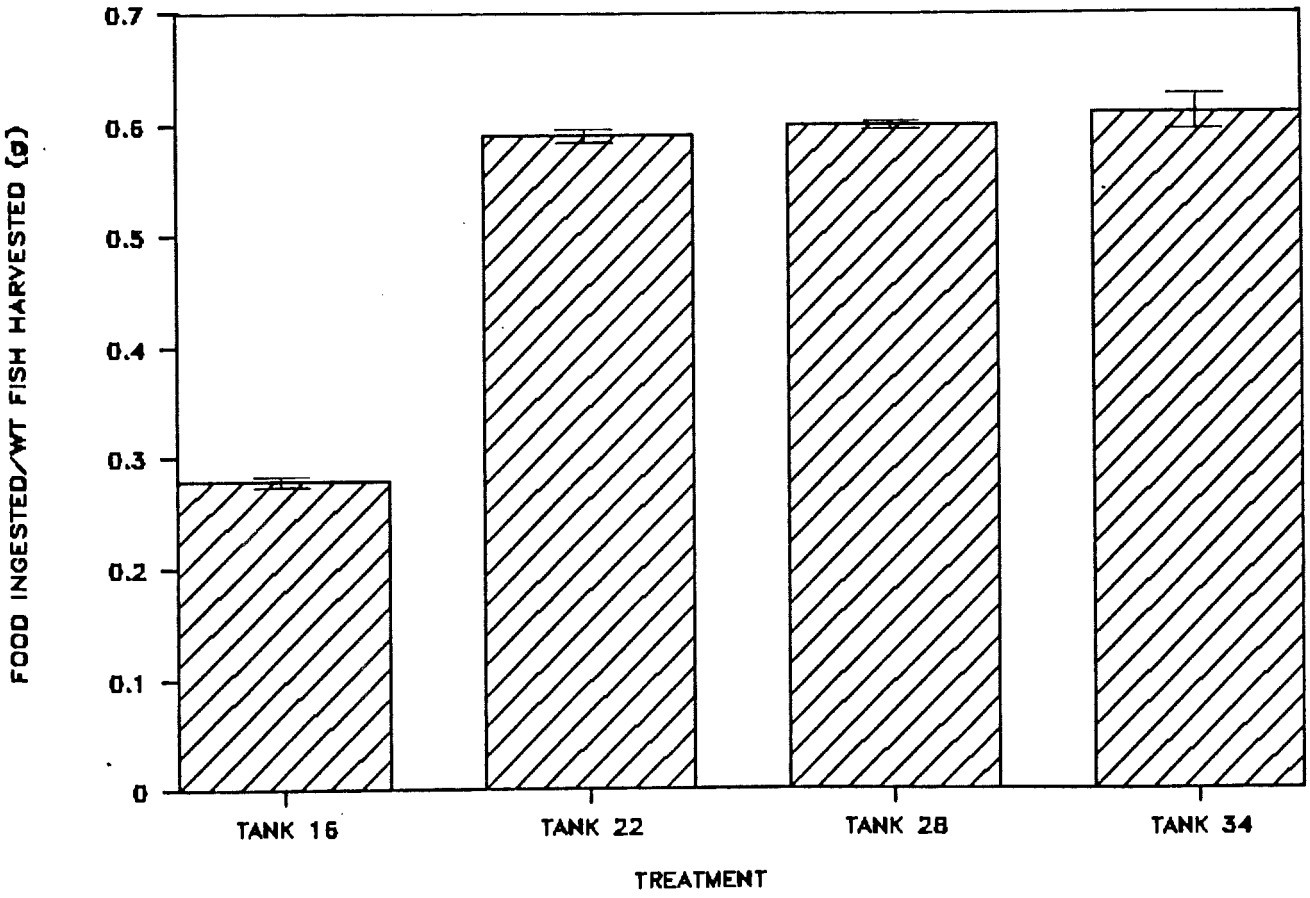

Figure 37. Feed conversion (C) of black bullhead maintained for nine weeks at 16, 22, 28 and 34 °C.

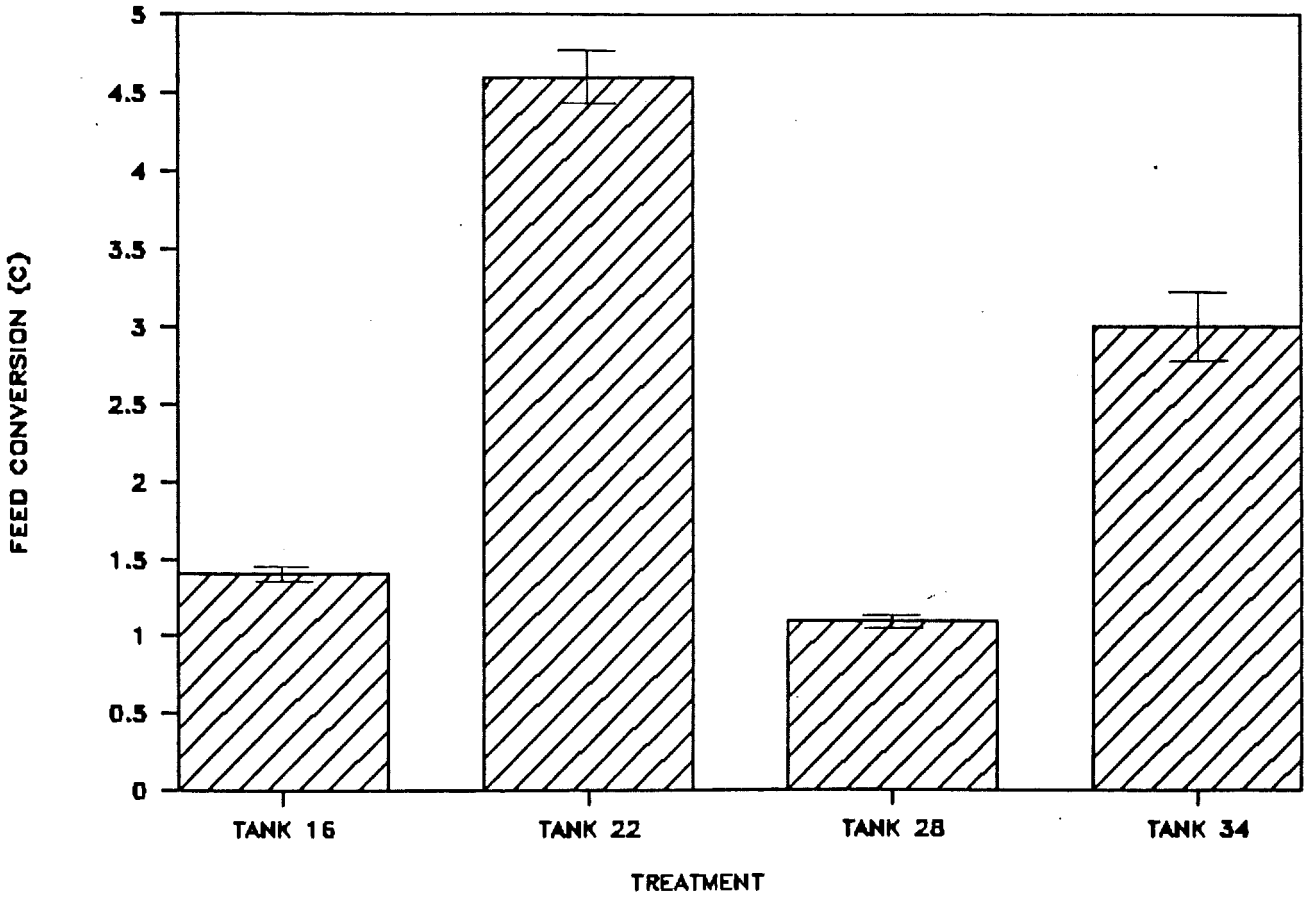

Figure 38. Percentage of body weight ingested daily by black bullhead in Tank 28A. Fish were weighed on days 1, 14, 43 and at harvest; no food was provided the day before and after weighing.

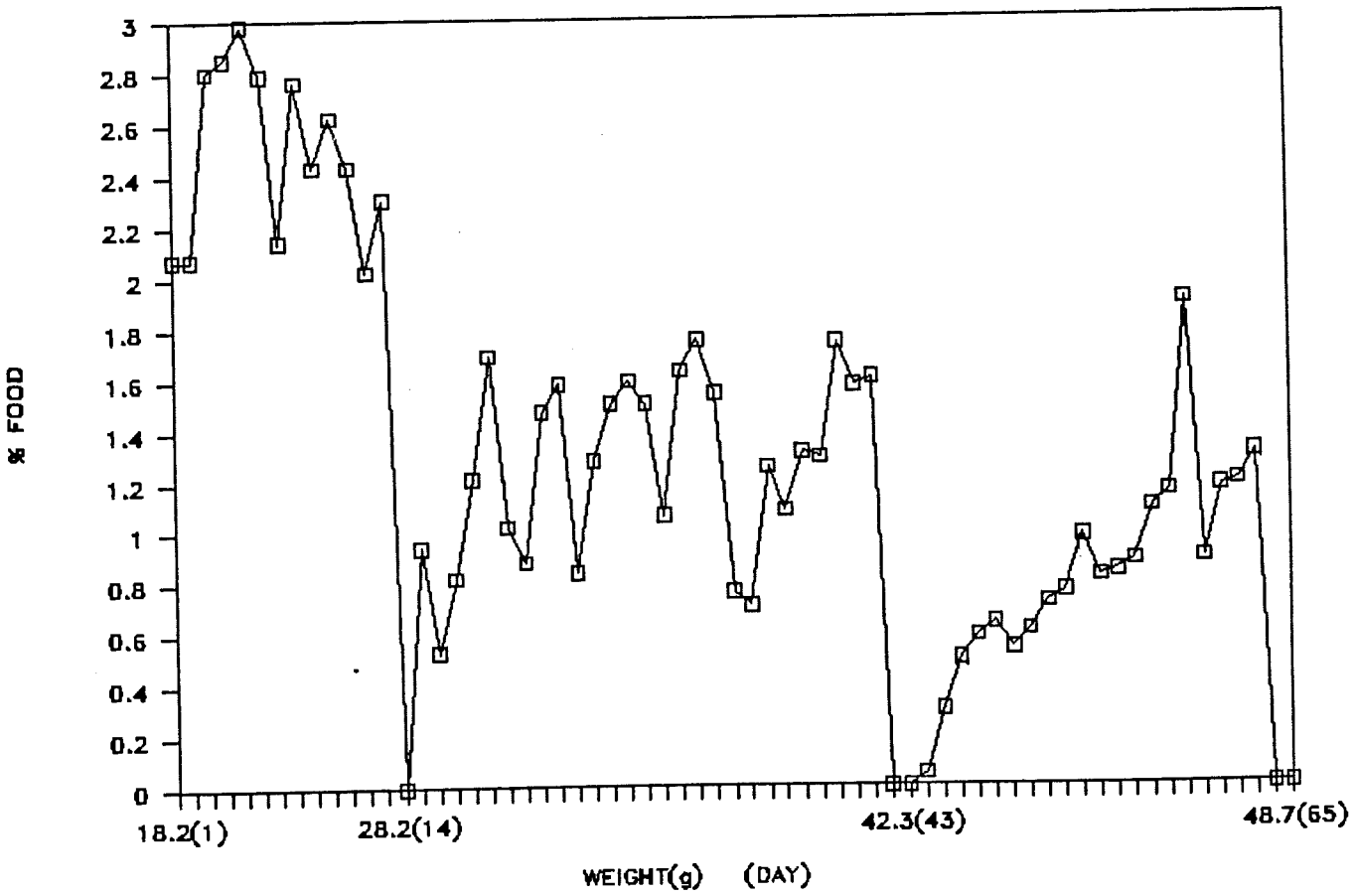

Figure 39. Percentage of body weight ingested daily by black bullhead in Tank 28B. Fish were weighed on days 1, 14, 43 and at harvest; no food was provided the day before and after weighing.

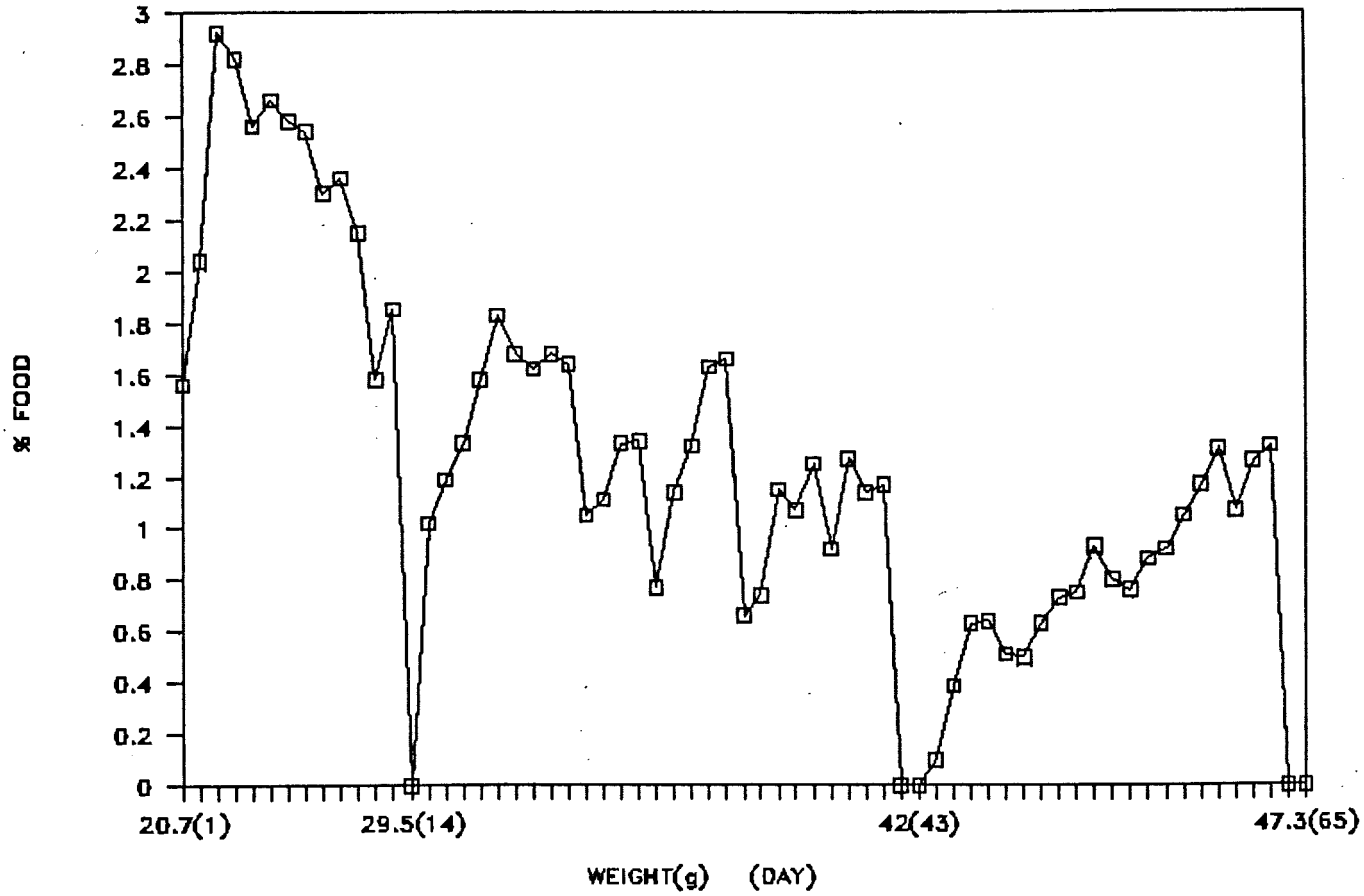

Figure 40. Percentage of body weight ingested daily by black bullhead in Tank 28C. Fish were weighed on days 1, 14, 43 and at harvest; no food was provided the day before and after weighing.